AD-A140 030 ONR-SPONSORED MEETING TO DISCUSS SOUTH ATLANTIC AND INDIAN OCEAN PHYSICAL OCEANOGRAPHIC RESEARCH(U) LAMONT-DOHERTY GEOLOGICAL OBSERVATORY PALISADES NY 1/1

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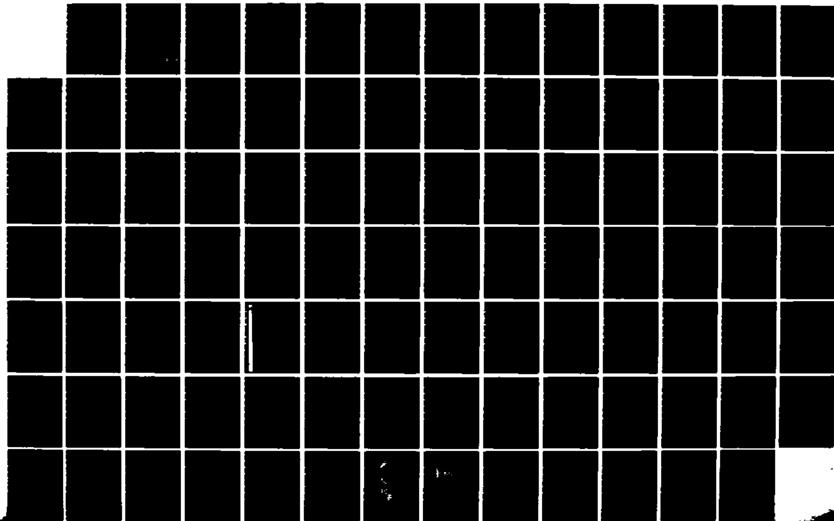

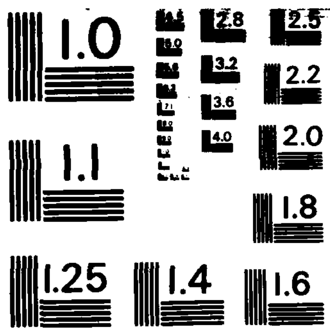
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22 March 1983

ONR-Sponsored Meeting to Discuss South Atlantic

and Indian Ocean Physical Oceanographic Research.

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Lamont-Doherty Geological Observatory of
Columbia University,
Palisades, NY 10964
Grant No. TO-0029

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	3.	Douglas Boudra, RSMAS/MPO, University of Miami
X	4.	Otis Brown, University of Miami
	5.	Robert Chase, Woods Hole Oceanographic Institution
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	9.	Gerald Gotthardt, NORDA/SEAS
X	10.	Stefan Hastenrath, University of Wisconsin
	11.	William Holland, NCAR
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X	17.	Johan Lutjeharms, South Africa
X	18.	James Luyten, Woods Hole Oceanographic Institution
X	19.	Afranio De Mesquita, Brazil
	20.	Ken Mooney, NOAA/OCAR
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	23.	Hsien Wang Ou, Lamont-Doherty Geological Observatory
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X	28.	Gilles Reverdin, France
X	29.	Gunnar Roden, University of Washington
	30.	Thomas Rossby, University of Rhode Island
X	31.	Will DeRuijter, CIMAS, University of Miami
X	32.	Friedrich Schott, University of Miami
	33.	William Smethie, Lamont-Doherty Geological Observatory
	34.	Thomas Spence, Office of Naval Research
X	35.	John Toole, Woods Hole Oceanographic Institution
	36.	Robert Wall, NSF
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	38.	Robert Willems, Office of Naval Research
X	39.	Walter Zenk, Federal Republic of Germany

Summary of Research Interests

Expressed at the ONR-Sponsored Meeting

on Oceanography of the Southern Ocean (a la ONR)

Held at L-DGO 22 and 23 February 1983, by Convener A. L. Gordon

I have prepared a table listing the research interests expressed by the meeting participants and others. This list is most likely not complete since oceanographers not present at the meeting or whom did not send me a statement of research interest might have something to add.

Please see the individual statements for further details, and I assume you may contact that person directly. This should be encouraged as an aid in making best and most efficient use of the ONR Southern Ocean research funds and ship availability.

I also prepared three time-phase diagrams in which the field research interests are given for the western South Atlantic, eastern South Atlantic and Indian Ocean. For mooring work, it is assumed a ship is needed at the start and end and maybe in the middle of the time-phase line.

No attempt at setting priorities nor of determining the total amount of ship time and research support has been made. I assume that when this is done, it would be clear that not all of the research can be carried out. However, if people remain flexible and communicate with one another, I believe groupings in space and time for the field research programs could be designed which would maximize the science output. In this regard, some consideration of the ship support required for the marine geology and geophysics program might even streamline the required support further.

Comments

(1) Indian Ocean: There seems to be a crescendo of interest in the 1985-1986 into early 1987 period. A start in 1985 with more intensive work in 1986 into early 1987 seems likely. The characteristics, sources and fronts of the Agulhas system and its retroflection seem to be the focus of interest.

(2) South Atlantic Ocean - East: There is less interest here. Perhaps it could be accommodated as part of the western Indian Ocean research.

(3) South Atlantic Ocean - West: There is much interest for work in the Brazil current system and its confluence with the Falkland current. Work is spread out from late 1984 to 1987: regional CTD in late 1984 to early 1985, with abyssal circulation moorings and two upper layer moorings and mid-level drifters in 1985 into 1986, and SOFAR/drifter

work in 1986-1987. I assume CTD work would bracket the mooring experiments and be carried out at the time of drifter/SOFAR deployment.

It may be difficult to do the western South Atlantic work at the same time as the western Indian Ocean work, but with a little planning and some changes in the timing of experiments, I think we can get a lot of the proposed work done.

We all eagerly await word from ONR about the actual amount of research money they will have for the Southern Ocean work, and for any specific guidance to the proposers of reserach. Again, I encourage people to be flexible and try to coordinate work with others who have expressed interest in the same or adjacent regions.

TABLE I. Research Interest.

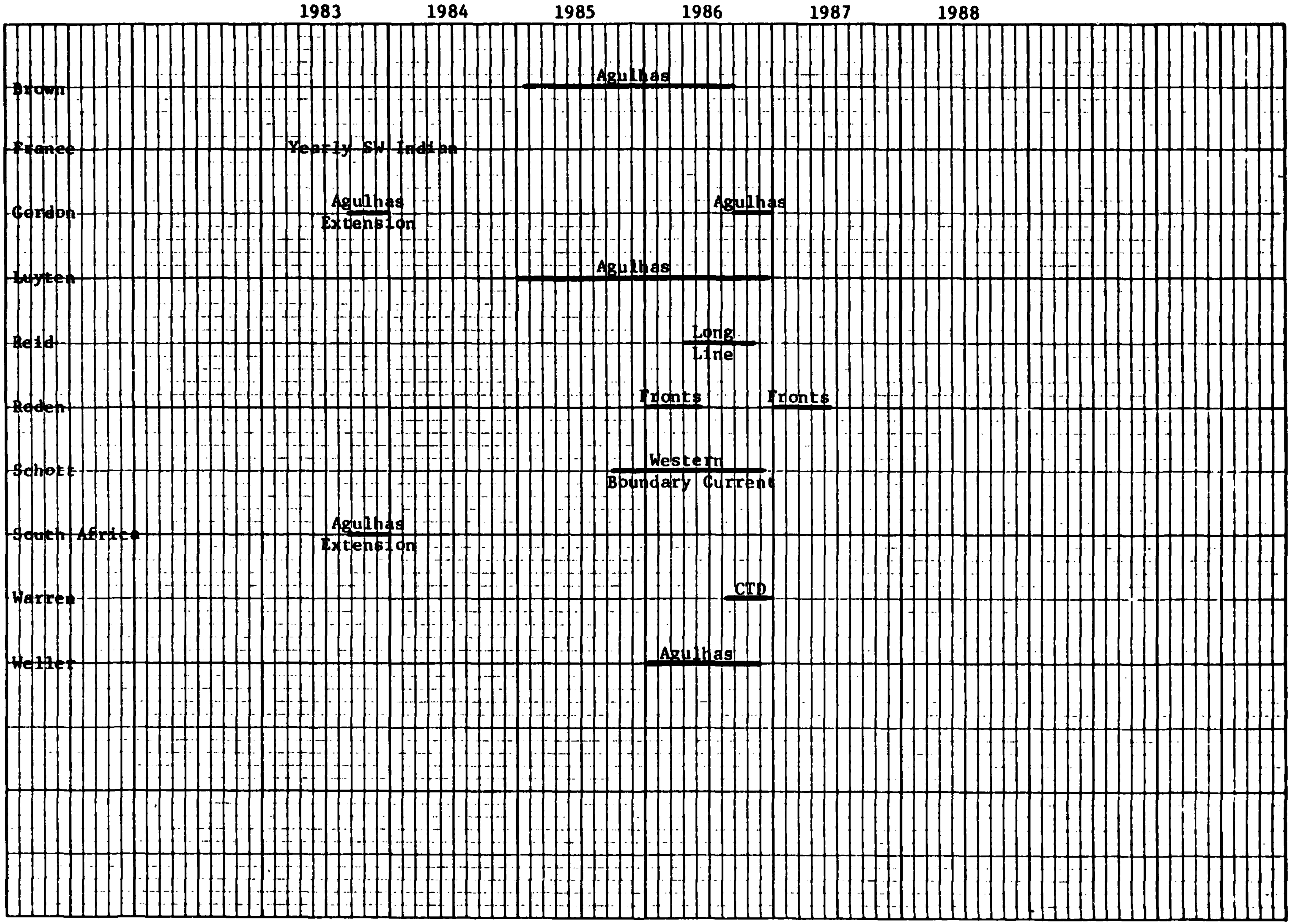
Who	What	Where	When
J. Apel	Satellite Altimeter	Regional	1985-1986
L. Armi	Sverdrup Interior CTD/Moorings	Central South Atlantic	Early 1986 and 1987
D. Boudra	Modeling	Agulhas Retroflection	
O. Brown	Drifters and Satellite IR Study	Agulhas	1985-1986
		Brazil Current	1986-1987
D. Evans	Brazil Current	24°S	Twice in 1983 (funded) & twice in 1984
	Brazil Current	32°S	Twice in 1984 & twice in 1985
S. Garzoli	Brazil-Falkland Confluence - Moorings	SW Atlantic	1985-1986
A. Gordon	Agulhas Current	South of S. Africa	Late 1983 (funded)
	Brazil-Falkland	SW Atlantic	Late 1984
	Agulhas Current	South of S. Africa	Late 1985 or late 1986
W. Holland	Modeling	Subtropical Gyre	
W. Jenkins	TTO	Western S. Atlantic	1984-1985
	TTO	Eastern S. Atlantic	1985-1986
	TTO	SW S. Atlantic	1986-1987
T. Keffer	Potential Vorticity		
R. Legeckis	Satellite IR	Western Boundary and Fronts	
J. Luyten	Agulhas Current	Agulhas Current South of S. Africa	1985 and 1986

TABLE I (continued)

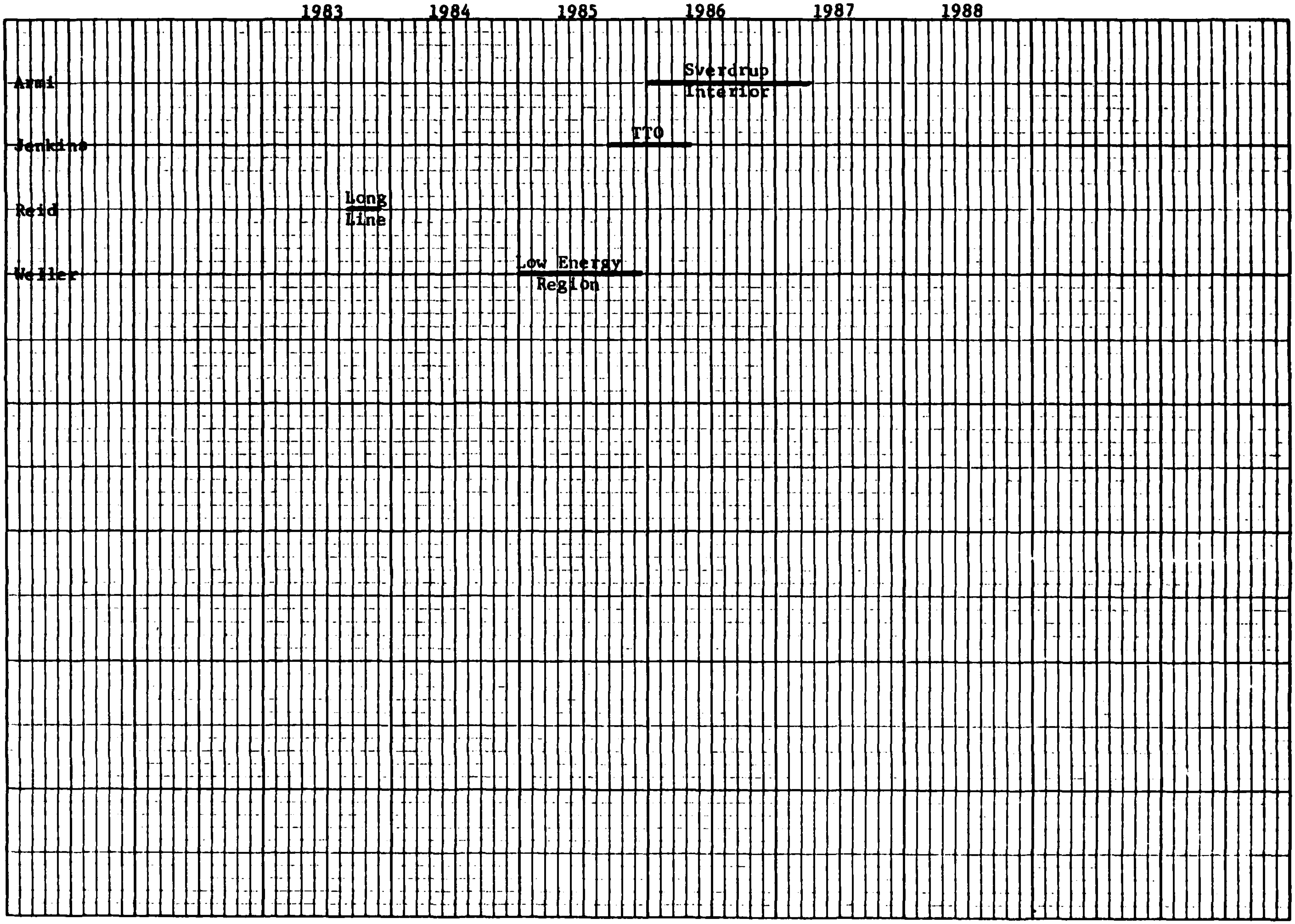
Who	What	Where	When
M. McCartney	CTD Section	11°S/22°S	February 1983 (funded)
	CTD Section	Western S. Atlantic	Late 1984
W. Nowlin	Antarctic Bottom Water Monitoring CTD/Moorings	Falkland Fracture SW Atlantic	Late 1984 and early 1986
B. Owens/ P. Richardson	SOFAR/Drifters	Western S. Atlantic	1986-1987
J. Reid	Long Line	0°	October 1983 (funded)
	Long Line	Indian Ocean	1986 or 1987
G. Roden	Frontal Zones	SW Atlantic	Early 1984 and early 1985
	Frontal Zones	SW Indian	Early 1986 and early 1987
T. Rossby	Deep Drifters in Antarctic Inter-metiate Water	Western S. Atlantic	1985
W. DeRuijter	Modeling	Agulhas Retroflection	
F. Schott	Western Boundary Currents - Drifter/ CTD/Moorings	Western Indian	Late 1985 to late 1986
J. Toole	Fine/Microstructure Free Fall Probe	Brazil Current	Late 1985
B. Warren	CTD Section	11°S/22°S	March 1983 (funded)
	CTD Section	Indian(?)	Late 1986
R. Weller	Low Energy Region Mooring	SE Atlantic	1985
	High Energy Region Mooring	Agulhas	1986

OTHER COUNTRIES: SEE STATEMENTS AND ATTACHMENTS

INDIAN OCEAN (INCLUDING AGULHAS SYSTEM)



SOUTH ATLANTIC OCEAN - EASTERN SECTION



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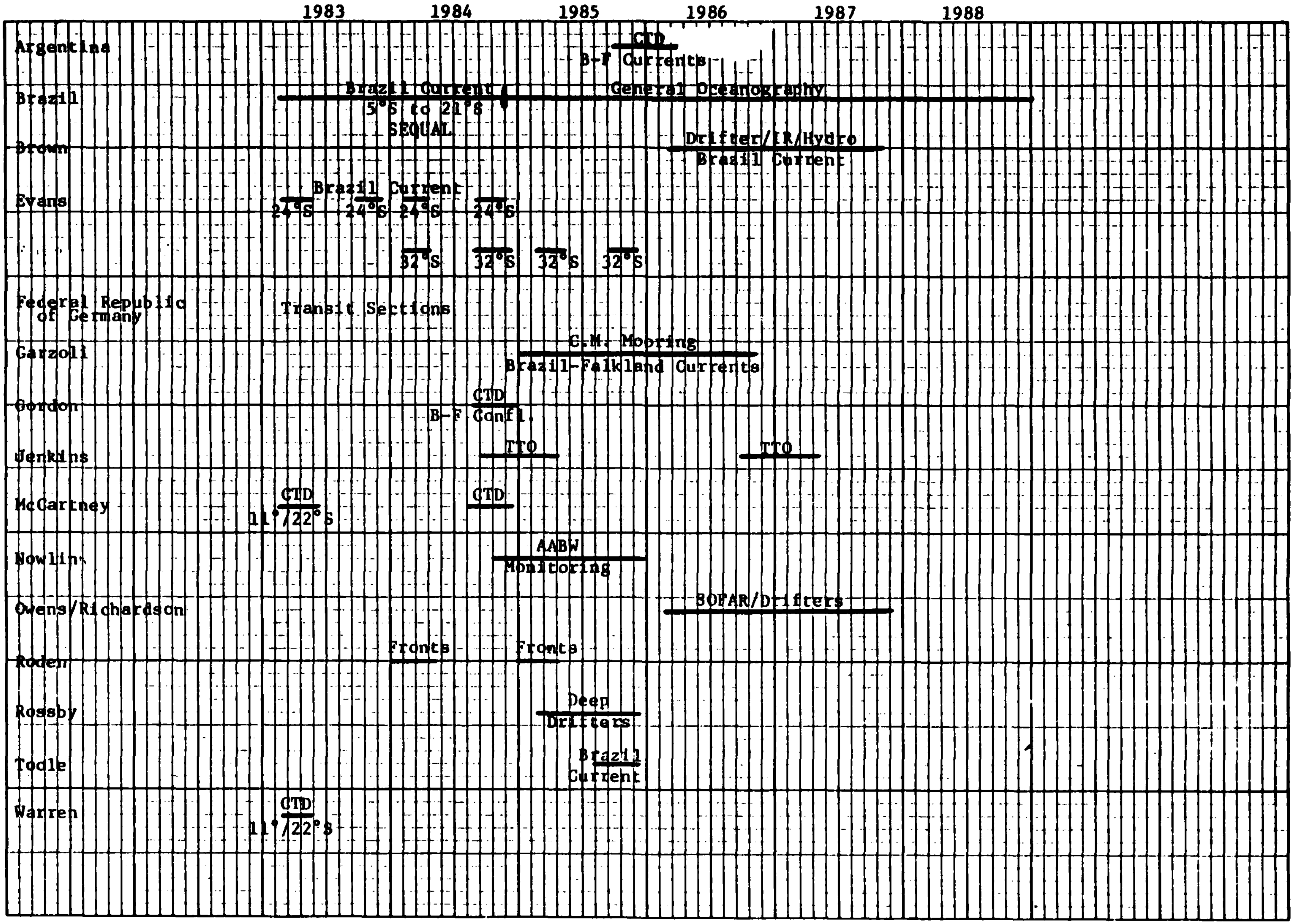


John R. Apel

The Geosat altimeter data can be used in studying mesoscale variability, significant wave height, and wind speed in the Agulhas Current and surroundings, with questions as to the relationships between wind stress, surface current variations, and wave generation being paramount. We also want to examine earlier altimeter data for information that might guide the design of the field component.

L. Armi, Scripps Institution of Oceanography

Two Views of the South Atlantic Subtropical Gyre

By adopting a CTD, hydrographic sampling strategy which optimizes our ability to compute property distributions and density surface positions in all three spatial directions, over a scale of ∿1000 km, specific dynamical and mixing questions can be asked and answered about the subtropical gyres. In the North Atlantic, balances of salt, oxygen and potential vorticity could be examined in detail (Armi and Stommel, Four Views of the North Atlantic Subtropical Gyre, 1983, in press, J. Phys. Oceanog., abstract attached). Some aspects, as best we could determine were stationary, surprisingly some aspects, in particular the dynamical signature of the North Atlantic subtropical gyre itself, vary.

Proposed would be two views of the South Atlantic, positioned at ∿27°S and East of the Mid-Atlantic ridge. Imbedded within the sampling plan would be a small current meter array to answer questions regarding mesoscale current variability and associated time scales which cannot be answered by hydrographic sampling alone.

Four Views of a Portion of the North Atlantic Subtropical Gyre

L. Armi and H. Stommel
1983, J.P.O., in press

Data from four cruises to the "β-*triangle*" centered at 27°N, 32°30'W were smoothed by fitting second-degree polynomials at each of about 30 different density surfaces. The density intervals were $\Delta\sigma_p = 0.3$ ‰, corresponding to about 50 db intervals in pressure. From the polynomials, determination was made of central values, horizontal deriviatives and laplacians of the fields of pressure, salt, oxygen and dynamic height. In addition, maps of the fits and deviations of each station from the smoothed fits were produced.

From the steady advective diffusive equation and the smoothed fits to the salt, oxygen, and dynamic height fields, the lateral isopycnal diffusivity was estimated to be $K_H \sim .5 \times 10^3\ m^2/s$. Although the salt field was reasonably stable from cruise to cruise, the variability of the baroclinic velocity shear was found to be as large as the baroclinic shear itself. The maps suggest a wobble of the gyre. The standard deviation of the fluctuations at each station from the smoothed fits, when normalized by the gradient, $l' = s'/|\nabla S|$, gives the mixing length of the horizontal turbulence. This was found to be ~80 km, presumably due to mesoscale turbulence. These fluctuations were all found, with one exception, to be normally distributed, suggesting the suitability in the subtropical gyre of a Fickian gradient transport diffusion. The one notable exception to the normal distribution was the discovery at one out of 143 stations of relatively undiluted Mediterranean water. The anomaly of salinity was as large as 0.65 ‰ or 20 standard deviations. A crude estimate suggests that the flux divergence due to the anomaly is approximately an order of magnitude less than either the advective or diffusive flux divergence.

There is a range of densities over which horizontal gradients of potential vorticity are small or nearly indeterminate. This range of densities intersects the ocean surface where the wind stress curl produces downwelling at the base of the Ekman layer. Deep density surfaces which intersect further north at upwelling latitudes have strong potential vorticity gradients.

O. Brown | RSMAS
D. Olson |
R. Evans |

INTERCOMPARATIVE STUDIES OF FRONTS AND EDDIES ASSOCIATED WITH WESTERN BOUNDARY CURRENTS

GOAL:

DELINEATION OF TEMPORAL AND SPATIAL SCALES FOR FRONTS AND EDDIES IN THE SOUTHERN OCEANS, INCLUDING AN INTERCOMPARISON WITH SIMILAR FEATURES IN THE NORTH ATLANTIC.

SPECIFIC STUDIES:

INFLUENCES OF TOPOGRAPHIC VARIATIONS ON EDDY DYNAMICS

LARGE SCALE HORIZONTAL SHEAR INFLUENCES ON EDDY STRUCTURE

PROPERTIES OF TRANSITION REGIONS - NW ATLANTIC SLOPE WATER VS AGULHAS REGION AND BRAZIL - FALKLANDS CONFLUENCE

KINEMATICS OF SURFACE FRONTS IN THE VARIOUS REGIONS BASED ON SATELLITE AND LAGRANGIAN TECHNIQUES

LARGE SCALE FRONTAL PATH DETERMINATIONS BASED ON SATELLITE OBSERVATIONS

Studies of the Brazil Current Transport

David L. Evans
Graduate School of Oceanography
University of Rhode Island

It has been repeatedly pointed out that there are no direct current measurements in the South Atlantic. In particular no direct current or transport measurements have been made in the Brazil Current. In addition to the routine wish to have that data, several basic issues need resolution:

1) How much (if any) transport gets past the sea-mounts near 20°S?

2) Is there barotropic (how large) flow associated with the Brazil Current? Does it extend on to the shelf?

3) Does the AAIW flow north or south along the Western South Atlantic boundary?

4) Does the transport of the Brazil Current increase downstream?

5) How strong is the transport in the supposed recirculation region?

6) Does the strong seasonal signal of position and magnitude in the wind stress have a correlative in the Brazil Current?

7) Is the Brazil Current between 19°S and 32°S characterized by meanders and eddies or by "straight" streamlines?

8) Is the reported northward flow offshore of the Brazil Current always present or only apparent due to unresolved eddies and other sampling problems?

We have begun to address these questions with Pegasus sections at 24°S and between the seamount at 20°S. Plans call for 2 or 3 cruises this year. An additional section at 30-32°S should be added in 1984 with a minimum of 2 and preferably 4 cruises per year. I would hope to continue the work through 1985 using U.S. and Brazilian ships. Items 7 and 8 above may require lengthening of the lines offshore. Items 6, 7 and 8 will be addressed partially through the analysis of satellite thermal IR data.

Quasi-Stationary Extensions of the Brazil and Agulhas Currents

Arnold L. Gordon

My interests are directed towards the 3-D thermohaline structure of the Brazil and Agulhas current extensions, including the frontal structure and mixing at their confluence with subantarctic water, mesoscale structures within the extensions and the effects of the deep winter mixed layers formed within the extensions on thermocline ventilation.

It is my intent to work in coordination with mooring, drifter, geochemical and satellite data studies to learn about the intensity of overshoots characteristic of the Brazil and Agulhas current. Of special interest in the latter is the retroflection region near 15°E and possible leakage of Indian Ocean water into the South Atlantic Ocean.

In December 1979 and January 1980 I studied the Brazil/Falkland confluence. In 1983 I will study the Agulhas current. I consider these "first cut" studies. In 1984 and 1985 or 1986 I will take the opportunity offered by the ONR Southern Ocean initiative to more fully investigate each system:

Brazil -- 1984

Agulhas -- 1985 or 1986,

preferably late in the year in each case.

Thoughts on
Southern Oceans Studies Program

This generous program in the Southern Oceans should keep an open perspective on problems of oceanic heat budget and transports. The transports of heat and freshwater offer valuable constraints as needed for the understanding of ocean circulation, a stated major concern of the program. Moreover, assessments of the continuity of properties in the Southern Oceans would provide a welcome Southern "closure" for global budget and transport studies. Issues of particular interest are as follows.

1. The thermal regime of the three Southern Oceans differs greatly, the South Atlantic being by far the coldest. A qualitative understanding of these contrasts is an elementary task. The longitude-dependence of ice output from Antarctica may have to be considered in addition to factors of ocean dynamics. The appropriate approaches may include Antarctic ice mass budget studies (Budd et al., 1971) and satellite sensing of the Southern Oceans.

2. Three independent approaches have been applied to estimate meridional heat and freshwater transports in the Southern Oceans, namely (a) evaluation of the surface budget, and subsequent integration with latitude (Hastenrath, 1981, 1982; Gordon, 198~~2~~1); direct evaluation from zonal hydrographic sections (Bennett, 1978; Fu, 1981); and (c) estimate of the divergence of zonal property transport in the Antarctic circumpolar current from meridional hydrographic sections (Georgi and Toole, 1982). The latter two methods (b) and (c) do not account for interannual variability and annual cycle and are thus not directly comparable to method (a) which refers to multiannual mean conditions. Results from the three approaches differ considerably, presumably in part due to interannual variability. Repeated hydrographic sections and evaluations of the surface budget during this multiannual program may permit updated estimates of property transports, which in turn are relevant to the explanation of ocean circulation.

From: T.KEFFER
To: R.WILLEMS,L.GOODMAN,T.SPENCE
CC: T.KEFFER,E.SODERLAND
Subj: FY 1984 PLANS

I apologize for my necessarily vague future plans in my 9 February planning letter. I wanted to wait until after the Lamont planning meeting before committing myself to something firmer. So here is a short update of my ONR plans for FY 1984.

Currently, I have ONR support to study the potential vorticity field of the North Atlantic. I will be proposing in this spring's omnibus to continue this analysis into the South Atlantic. At the Lamont planning meeting I showed a preliminarly contour map of the q field at sigma theta = 27.15. As you may recall, it looked astonishingly different from the North Atlantic, with much more extensive homogenization. If we wish to understand the thermocline density field, it is essential that we explain these differences.

To do this, I will be proposing a two part approach. First, will be a more careful and comprehensive mapping of the South Atlantic q field. The hydrographic sections scheduled to be taken by McCartney, Warren, and Reid should prove very useful for this. I will be communicating with them.

Second, will be a collaborative modelling/theoretical study of the S. Atlantic will Bill Holland. He and I have already discussed the types of models that will be necessary and he has made arrangements to have them run at NCAR. I will be participating in the subsequent analysis of the q field and its interaction with the Antarctic Circumpolar Current.

I anticipate asking for 4 months of support and a budget in the $34-38K range.

Again, sorry for the delay.

Action?
Line Connected

Proposed Satellite Coverage of
South Atlantic and Indian Ocean

R. Legeckis
NOAA/NESDIS
1/25/83

The southern oceans could be monitored by the polar orbiting TIROS series of satellites using the AVHRR at visible and thermal infrared wavelengths. The 4 km spacial resolution data (GAC-global area coverage) is available globally twice each day. At this resolution, it is possible to resolve the temperature signature of the western and eastern boundary currents, eddies, and fronts. The effort to utilize the GAC data will be limited primarily by three factors:

--cloud cover

--quantity of satellite data to be gathered

--facilities to process the data for oceanographic applications

To get the project rolling, the following approach could be taken for the GAC data:

--Identify the GAC data that is sufficiently cloud free to warrant further attention. Catalog this information.

--Establish a digital data tape library of GAC data of the cloud free scenes. This will allow the data to be processed on interactive or other computers by various investigators.

--Processing can then proceed to convert the raw data to information required by an investigator.

A second component of the satellite work could involve the AVHRR data at a spacial resolution of 1 km (LAC - Limited Area Coverage). The difference between the LAC and GAC is that the LAC must be recorded over a specified area for a specified time period. Due to tape recorder limitations, the LAC data are usually not available twice per day. However, specific areas could be targeted for coverage at daily or less frequent intervals. Possible targets would be the Brazil, Agulhas and Somali Currents. Monitoring of the global GAC data set may also reveal the need for higher resolution coverage of other areas.

E

R. Legeckis 2/83

Collecting TIROS AVHRR infrared data since 1979 until 1984 of oceanic frontal zones associated with the following:

- Arabian Sea
- Agulhas Current Retroflection area
- Benguela Current
- Brazil-Falkland Confluence
- Circumpolar Front in vicinity of 45 to 55°S

Purpose: Describe frontal interactions

Exploration of the Agulhas Current and its Retroflection

James Luyten, WHOI

The Agulhas current system is one of the most robust western boundary currents in the world's ocean. The Agulhas exhibits a number of phenomena such as retroflection, possible leaking of momentum into the Southern Atlantic Basin, and possibly distinct modes of separation from the continental shelf. Numerical modelling of this current system suggests that there is a vigorous deep eddy field and a recirculation comparable to that in the western North Atlantic. There are few direct observations of these phenomena, particularly in the deep ocean.

I propose to deploy a mooring array spanning the region of the possible recirculation, retroflection and leakage. The array consists of 10 moorings, deployed in early 1985 for two years duration, with current meters at 200 (or possibly 500), 750, 1500 and 4000 meters. The particular array design will evolve and rely in part upon results from the South Africans, modellers and the projected cruise to the Agulhas this October.

Study of Bottom Water Exchange Between Argentine Basin and Southern Ocean

W. Nowlin

Weddell Sea Deep Water (a variety of Antarctic Bottom Water) is available for exchange between the Weddell Sea and the Argentine Basin through two routes: Between the Mid Atlantic Ridge and the Islas Orcadas Rise and between the Islas Orcadas Rise and Falkland Plateau. Most of the exchange of the coldest, densest of this water probably takes place along the latter route, through the Falkland Channels. Proposed is a study of these exchanges and their effects.

Field work will include placing a yearlong array of moored instruments in the Falkland Channels plus oceanographic station measurements during deployment and recovery cruises. Those measurements would be made at both exchange routes and along the likely spreading axes; and would include CTD, oxygen, nutrients and transient tracers. We would like to begin the work in late 1984 or early 1985.

Principals involved in the planning include Thomas Whitworth, Worth Nowlin and Dale Pillsbury. We have approached Bill Jenkins for TTO measurements and input, and he expressed interest. The Argentine Antarctic Institute is interested in complementary studies to the southwest on distribution and flows of deep waters through the N. Scotia Ridge and in the Malvinas Escarpment.

We hope that through this study we can:

(1) Improve knowledge of the paths of spreading of dense water between the Argentine and Weddell Basins, including knowledge of the regional depth distribution of the stability stratum (near 2°C) marking the base of the Circumpolar Deep Water (CDW).

(2) Estimate meridional exchange rates of Weddell Sea Deep Water (WSDW) between Islas Orcadas Rise and Mid Atlantic Ridge.

(3) Obtain one-year mean of transport of WSDW through Falkland Channels.

(4) Obtain yearlong record of time variability of waters below CDW in Falkland Channels -- temperature and velocity fields.

(5) Investigate relationships between (4) and the variations of the overlying flow of the Antarctic Circumpolar Current.

(6) Obtain estimates of flow rates and time since exposure to surface layers of bottom waters and CDW through Georgia Basin and northeast of Islas Orcadas Rise through use of geochemical tracers.

(7) Investigate relationship between flow of WSDW through Falkland Channels and flow through the downstream gate (Vema Passage).

(8) Apply integral constraints to a layered model to study advection and diffusion within bottom waters in the Argentine Basin.

Brechner Owens

SOFAR floats are an obvious observation system to make exploratory direct current observations in the western South Atlantic since they would not be limited to a few locations, but would move throughout the basin. In a recent experiment, GUSREX, floats were launched along 55°W, from north of the Gulf Stream into the interior of the subtropical gyre. We have found that the floats give a good desription of both the local mean circulation and eddy variability and also the interconnection between the Gulf Stream and the North Atlantic Current. The local description is in agreement with one obtained using the 27 month long POLYMODE Array II moored currentmeter data. This experiment demonstrated that floats should be ballasted to at least two depths to describe the vertical structure. Both as a basic description of the physical oceanogrphy of the South Atlantic and as a test of ocean circulation models with a different environment than the North Atlantic, a similar exploration of the mean circulation and eddy variability in the South Atlantic is an attractive SOFAR float experiment. Based on the limited surface current information, the South Atlantic western boundary current system appears to be more complicated than the Gulf Stream system in the North Atlantic. The two boundary currents along the South American coast, the Falkland and Brazil Currents, appear to interact and converge into a jet flowing eastward into the interior of the basin. As a result, we would like to deploy floats in both current systems. As the floats are carried downstream and into the interior, they would give a broad, first order description of the flow in the western basin. Thus, the floats would provide a broad spatial coverage with relatively few instruments. Following the deployment scheme used in GUSREX, we would launch the floats in pairs of deep and shallow floats. To make best use of the tracking system, we would launch the floats at eight sites along 30°S from the Brazil Current into the subropical gyre extending to near the Mid-Atlantic Ridge. At the same time, we would launch floats at five sites along 45°S to explore the flow associated with the Falkland Current. Finally, we would also launch two float pairs in the confluence region to insure that floats enter into that region and flow downstream. We expect this deployment scheme should insure a reasonable first cut at maps of the eddy kinetic energy in the South Atlantic subtropical gyre and of the mean flow.

Gunnar I. Roden

My main interest lies in oceanic fronts of the South Atlantic and South Indian oceans and I would like to propose a systematic and coordinated study of such fronts, starting with the western boundary current (Brazil and Agulhas) fronts and their extensions. Because these fronts are likely to be strongly meandering, a three-dimensional field study would be most appropriate. The domain of study should be big enough to accomodate the dominant meander wavelength, say 2 pi times the Rossby radius of deformation, or about 300km by 300 km. The station spacing in the domain should be of the order of 30 km by 30 km to obtain adequate resolution. If possible, the station pattern should be repeated to assess the time variability. I believe such a study could be carried out in about 4 weeks in the working area.

The best results of field work come from a combination of preferably independent methods. In addition to the traditional CTD work, it would be most useful to deploy ten or so satellite tracked drifters to study the Lagrangianmotion in the vicinity of fronts and to make use of satellite images of the frontal area. In order to study the influence of atmospheric forcing upon fronts, the wind stress field must be known also; I think poleward of latitude 25, the stress of the geostrophic wind could be used as a first approximation.

Apart from oceanic fronts I have an interest in investigating long-wave perturbations in the South Atlantic and South Indian oceans. These perturbations could be detected by long meridional sections with closely spaced stations. I have found such perturbations in the North Pacific, with a wavelength of about 400 km and a wave amplitude up to 30 dyn. cm. The perturbations appear to depend upon season. Such perturbations affect the interpretation of hydrographic measurements, particularly transport calculations. Knowledge of such perturbations is important also in analyzing satellite altimeter data.

I have included in this letter several enclosures. Enclosure (1) is an attempt to list the main fronts of the South Atlantic and their characteristics, together with some outstanding questions. This listing is very preliminary, because I have glanced through only a few publications.

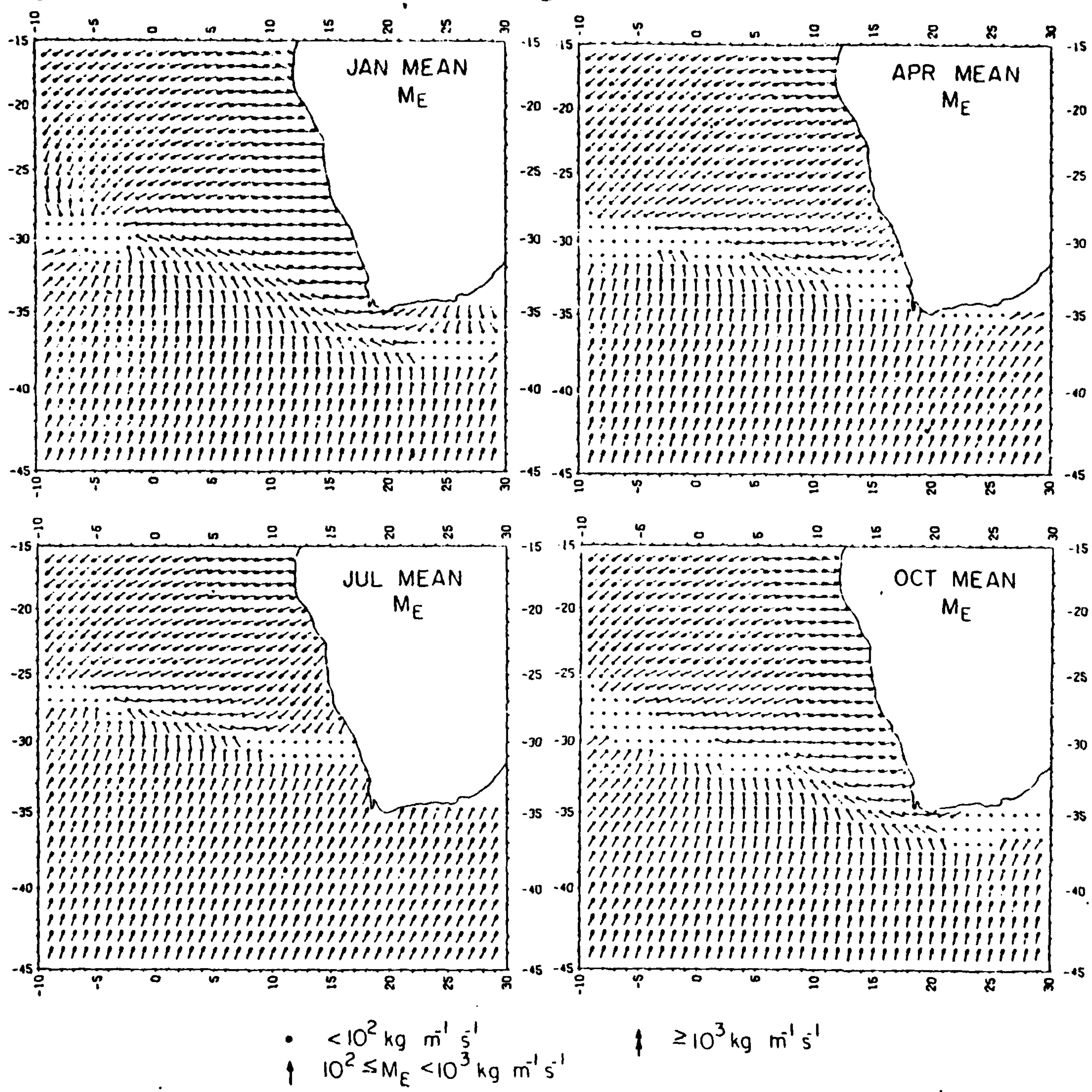
Enclosure (2) shows the Ekman transport field for four seasons, as derived from the stress of the geostrophic wind. The main feature here is the confluence of transports in the subtropics. This should indicate the approximate position of the oceanic subtropical frontal zone.

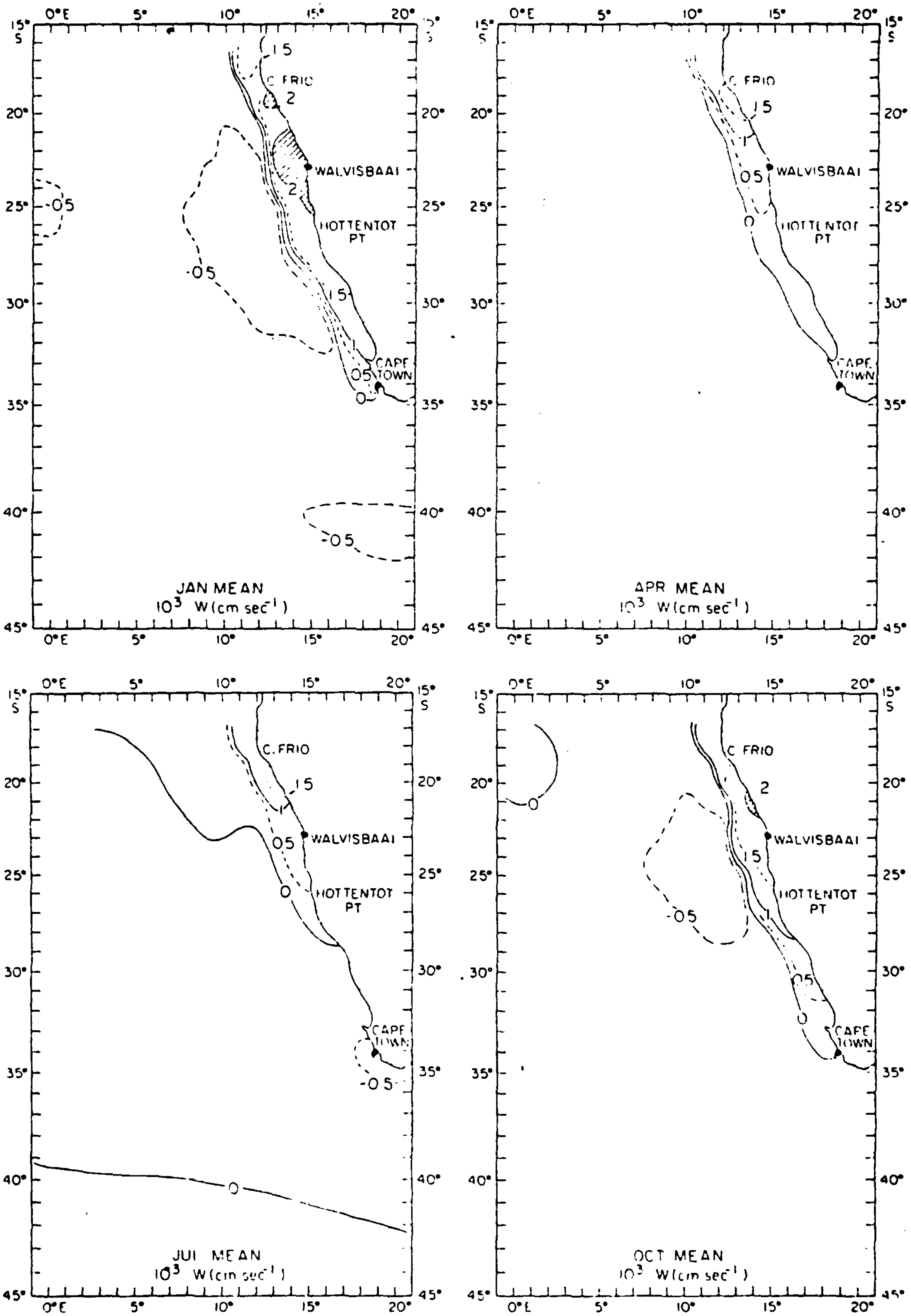
Enclosure (3) shows the vertical velocity as determined from the curl of the wind stress. It indicates the seaward extent of the southwest African upwelling region as seen through a large scale mesh (100 km by 100 km).

Enclosures (4) and (5) are examples of long-wave perturbations in the North Pacific, which can only be detected by long (2000 km or more) sections. I would not be surprised to find similar perturbations in the South Atlantic.

FRONTS OF THE SOUTH ATLANTIC A[illegible] SW-INDIAN OCEANS

FRONT	TYPE	CHARACTERISTICS	OUTSTANDING QUESTIONS
A. Brazil-Falkland front	boundary current front	highly baroclinic, strong deep, convoluted	3-D structure and variabil does it merge with subanta front?
B. Subantarctic front	wind-generated front in upper layer; in lower layer front probably due to deformation in geostrophic flow field	upper layer weakly baroclinic, lower layer moderately baroclinic, upper layer fronts are strong, but density compensating	3-D structure and variabi response to atmospheric forcing, resemblance to northern hemisphere front
C. Agulhas front	boundary current front	highly baroclinic, strong deep, convoluted	3-D structure and variabil recurvature of Agulhas cur and front
D. Subtropical fronts of the South Atlantic and the South Indian Oceans	wind generated frontal zones, in which there occur several fronts	fronts are moderately baroclinic, mostly confined to depths above the pycnocline. Fronts are of moderate intensity	3-D structure and variabil response to atm[illegible] resemblance to northern hemisphere subtropical fro
E. Antarctic front	circumpolar current front influenced by the wind field	often a frontal zone is observed in the upper layer, in which there occur several fronts. Numerous inversions and intrusive features	3-D structure and variabil circumpolar continuity, relation to atmospheric fo


JAN MEAN
M_E
APR MEAN
M_E
JUL MEAN
M_E
OCT MEAN
M_E
$< 10^2$ kg m^{-1} s^{-1}
$10^2 \leq M_E < 10^3$ kg m^{-1} s^{-1}
$\geq 10^3$ kg m^{-1} s^{-1}


JAN MEAN
10^3 W(cm sec^{-1})
C. FRIO
WALVISBAAI
HOTTENTOT PT
CAPE TOWN
APR MEAN
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JUL MEAN
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OCT MEAN
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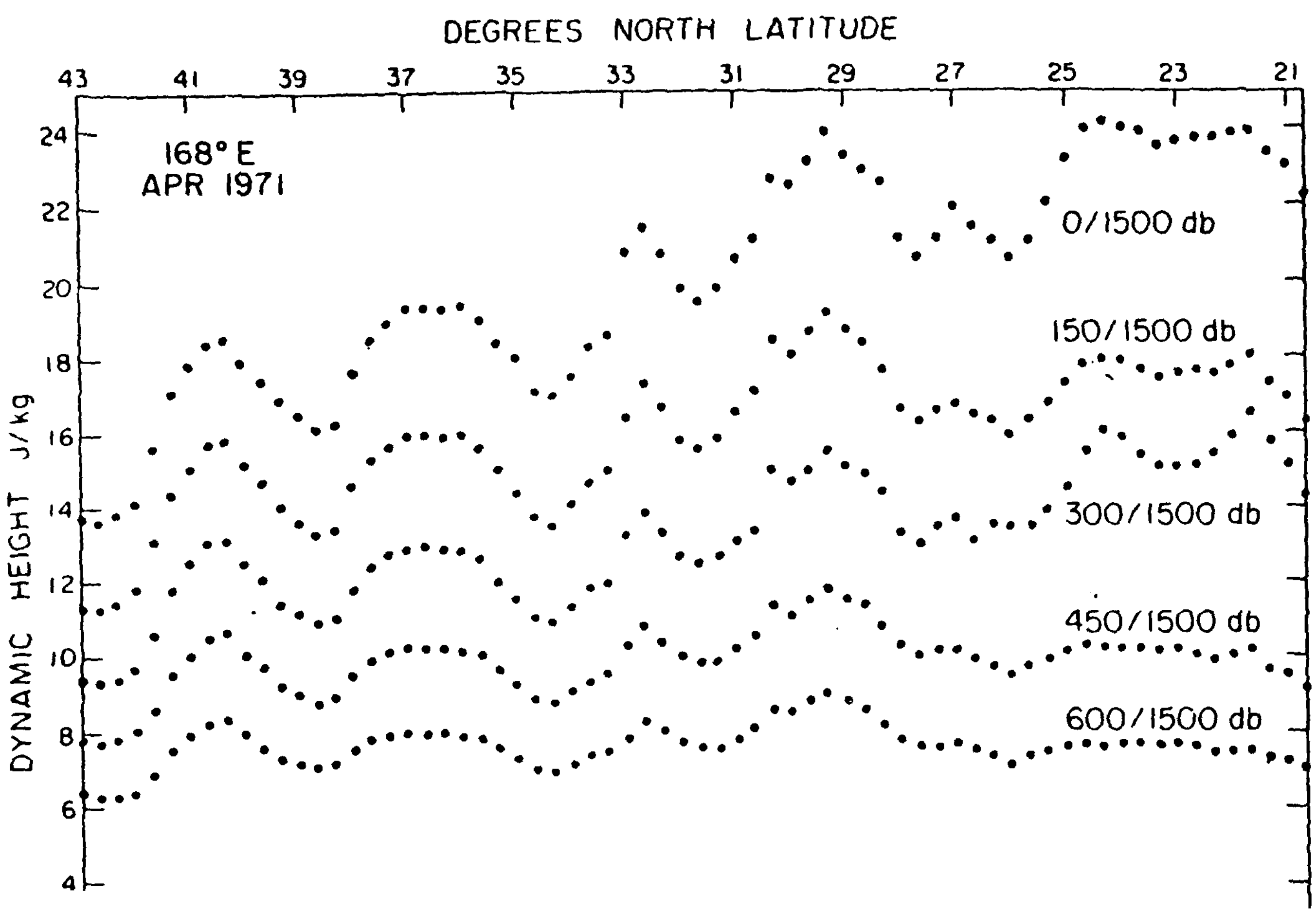
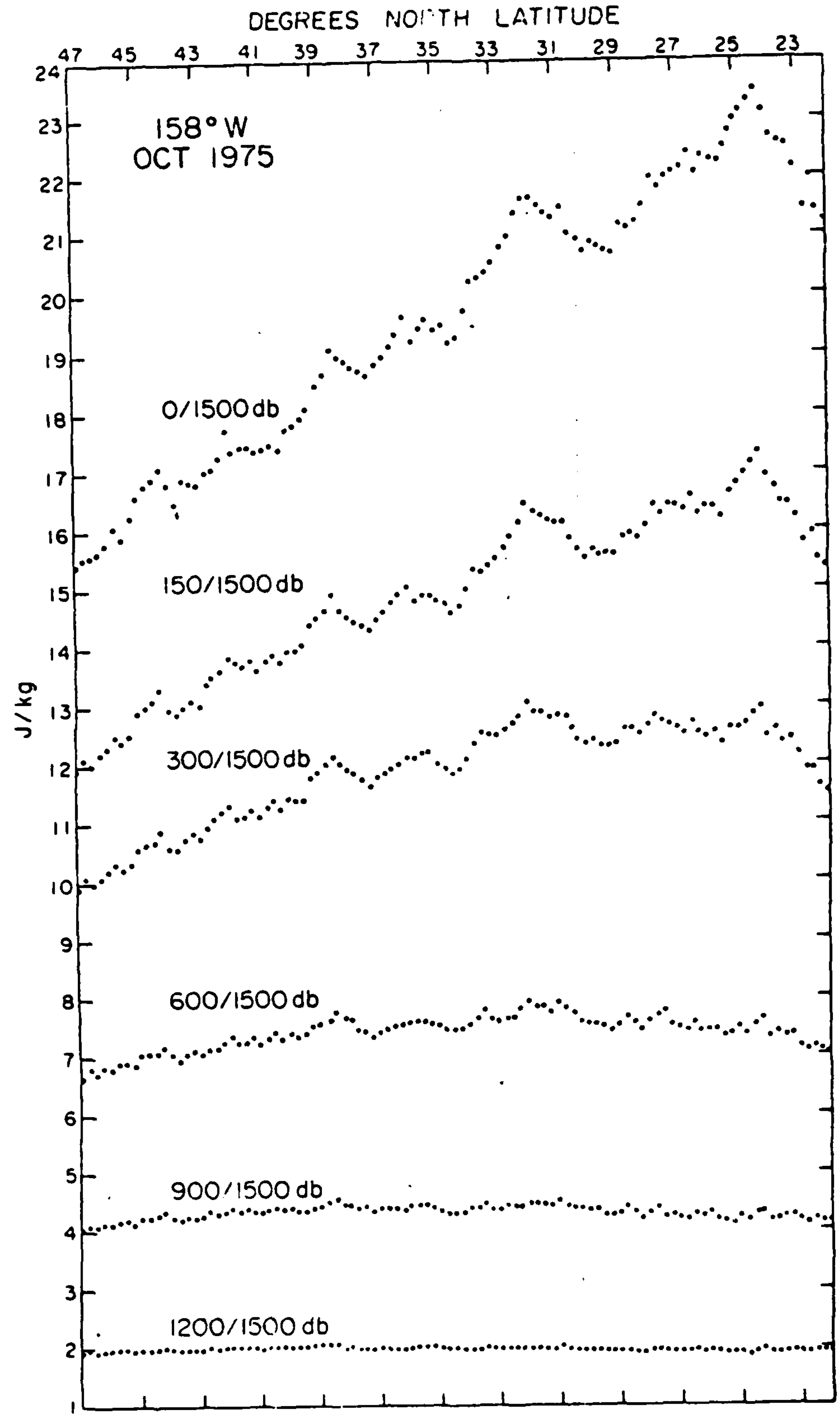

DEGREES NORTH LATITUDE
43 41 39 37 35 33 31 29 27 25 23 21
DYNAMIC HEIGHT J/kg
24 22 20 18 16 14 12 10 8 6 4
168° E
APR 1971
0/1500 db
150/1500 db
300/1500 db
450/1500 db
600/1500 db


DEGREES NORTH LATITUDE
158° W
OCT 1975
0/1500 db
150/1500 db
300/1500 db
600/1500 db
900/1500 db
1200/1500 db
J/kg

Will DeRuijter

Here are a few topics that might be relevant ones in connection to the Southern Ocean Studies Project:

- Effects of geometry; e.g. what role does the shape of the South African peninsula play in the overshooting dynamics?; what is the effect of the bottom topography?
- Is there a non-negligible seasonal variation in the system? (Again, especially in connection with Agulhas-leakage, possibly mainly below the upper layer.)
- How closed is the Southern Atlantic - Indian Ocean System? Is there a well defined subtropical wind-driven gyre within the system? What happens for instance in the South Australian - Tasmanian corner?
- Is mixing with especially the ACC a crucial factor in the determination of the large scale circulation pattern (as the modeling-experiments support)?
- What wind data are available (or should be obtained) over the area?
- Etc.

Most of the above questions are unanswered both from the observational and the modeling side. The outcome of our experiments has been very exciting and promising. I hope that in the future I can remain involved, in one way or the other, in the study of this unique area in the world ocean.

F. SCHOTT
RSMAS/University of Miami

PROPOSED FIELD EXPERIMENT IN THE WESTERN INDIAN OCEAN

The seasonal variability of the circulation in the equatorial and subtropical Indian Ocean is the most pronounced of all oceans.

While some progress has been made in the past few years in understanding the monsoon response of the Somali Current north of the equator, very little is known about the seasonal changes and other variability of the western boundary currents in the Indian Ocean south of the equator.

It is proposed to study the interaction of the zonal currents (South Equatorial Current, Equatorial Counter Current) with the western boundary (Somali Current, East Madagascar and Mozambique Currents) in both monsoon seasons with ship sections, moored stations and possibly drifters.

The experiment, as a rough first estimate, should consist of the following components:

1. East Madagascar Current: 3 moorings, repeated ship sections normal to the coast;
2. Mozambique Channel: 2 moorings, repeated ship sections across;
3. East African Coast, at the equator: 3 moorings, repeated ship sections normal to the coast;
4. Meridional ship sections from northern tip of Madagascar to $\sim 3^{o}N$;
5. There should also be seasonal repetitions of the meridional section run by the French between La Reunion and several degrees north of the equator.

The usefulness of drifters to be released along the proposed sections is being studied. It is hoped that an eventual drifter component of the experiment could, at least partially, be provided through cooperation with French scientists.

The experiment should really run over two years to get a feel for significance of seasonal differences seen; the obvious minimum duration is over two seasons. Moorings should be out for one year with possibility of a second deployment.

Additional measurements required from other groups for a better interpretation of the field experiment are:

- satellite SST data from around Madagascar and off Somalia;
- altimetry data from the whole tropical and subtropical Indian Ocean from GEOSAT
- wind measurements from buoys, ships or satellites (clouddrifts) in the Western Indian Ocean.

The experiment could start by late '85. Logistics could be greatly simplified through cooperation with the French CNRS who runs the "Marion Dufresne" twice yearly from Marseille to La Reunion.

William Smethie
Lamont-Doherty Geological Observatory

In Geochemistry we have recently acquired the capability to measure freon-11 and freon-12 at sea water. These gases have tremendous potential for tracer work because 1) they can be measured at sea within hours after samples are collected; 2) the atmospheric time history of these gases is well known and the signal is equally strong in the northern and southern hemispheres and 3) these gases are essentially inert.

I am interested in making freon measurements on cruises investigating western boundary undercurrents, midwater and abyssal circulation, deep and bottom water formation, and thermocline mixing processes. The projects presented at the planning meeting which appear attractive to me are the long line surveys proposed by Reid, the bottom water study in the Scotia Sea proposed by Nowlin, the drifter study in Antarctic Intermediate Water proposed by Rossby, and the hydrographic surveys of the Brazil and Falkland currents and the Agulhas Current proposed by you.

I think freon measurements can make a valuable contribution to these projects. The shipboard requirements for freon measurements are a 5-liter rosette for sampling, approximately 8 feet of bench space for equipment and 1-2 berths for analysts.

I am not sure what the next step is in the development of the Southern Oceans Study. I hope that tracer work will be included in early planning and I would be very interested in participating in this.

Exploration of Fine and Microstructure Variability
in Southern Hemisphere Western Boundary Currents

J. Toole, Woods Hole Oceanographic Institution

Previous sampling in the South Atlantic and Indian Oceans has revealed intense fine structure and the potential for salt fingering in the western boundary current regions of these basins. These data suggest that small scale mixing processes may be important in forming or modifying important water masses. However, direct microstructure measurements are necessary to quantify the rates of mixing. Additionally, it is clear from earlier studies that concurrent sampling on the fine and mesoscales is necessary for the understanding of the microstructure field and the interconnection between scales.

At present, design specifications for a fine and microscale velocity/temperature-salinity profiler are being drawn up by Dr. R. Schmitt and me at WHOI. We envision an instrument along the lines of the Total Ocean Profiling System (TOPS) of Dr. Hayes of P.M.E.L. augmented by microtemperature sensors to sample both vertical and horizontal variability. This instrument is ideally suited to the task of documenting the spatial variations in fine and microstructure intensity associated with the strong gradient regions of the southern hemisphere boundary current and to explore the relations between temperature, salinity and velocity variability on the fine scale, mesoscale current/water mass structures and the microstructure.

I believe exciting data can be obtained in the confluence and retroflection regions which will permit assessment of the water mass modifications that occur in these energetic zones. Data can be gathered "piggy back" style on standard hydrographic cruises thus limiting logistical requirements. Timing of fieldwork depends on instrument acquisition. Should procurement proceed directly, fieldwork could commence in mid to late 1985.

Summary

Robert A. Weller
Woods Hole Oceanographic Inst.

Plans: What, When, How

Early 85 - early 86. 12 month long setting of 3 surface moorings in a low eddy kinetic energy region; profiling velocity, conductivity, temperature in features with strong horizontal variability (0-200 m).

Early 86 - early 87. 12 month long setting of 3 surface moorings in high eddy kinetic energy region; velocity, conductivity, temperature profiles in upper 200 m.

Where

Low eddy kinetic energy region could be northwest of Agulhas in the "leakage" area; high eddy kinetic energy region could be northeast of Agulhas retroflection or near Brazil-Falklands confluence.

Why

1. What is the role of horizontal variability in air-sea interaction?

2. Contrast work on air-sea interaction done in northern hemisphere with southern oceans -- a unique opportunity.

3. Examine variability in different frequency bands (from eddy kinetic energy variability up to internal wave frequencies). Contrast with Bill Schmitz's findings in northern hemisphere. What fraction of the variability is related to local atmospheric forcing?

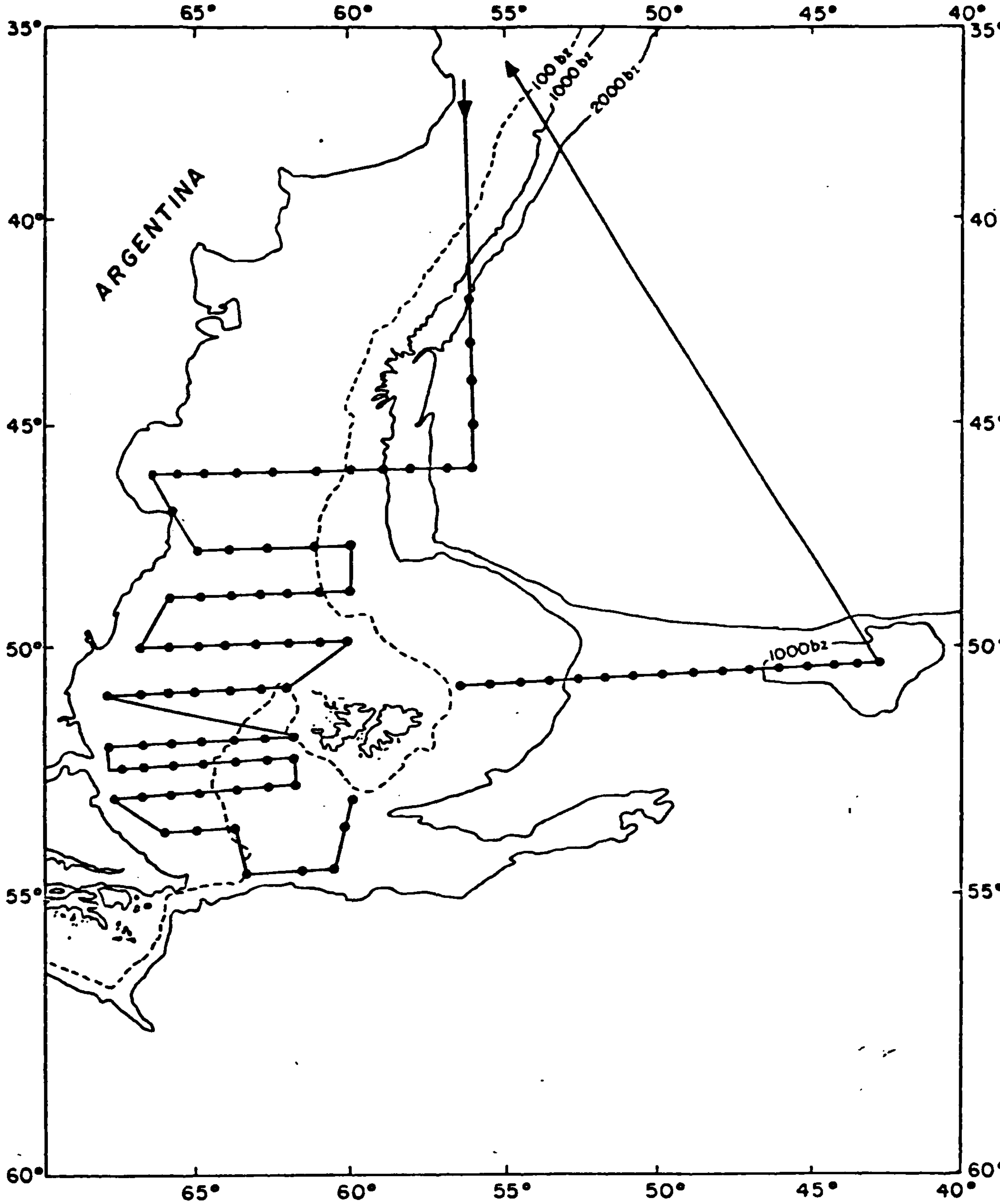
ARGENTINA A. Piola

ONR Southern Ocean Research Meeting
Future Work Planned by Argentina

The Naval Hydrographic Office of Argentina has recently designed a three year program to study some aspects of the physical, chemical and biological oceanography of the coastal waters and southwestern Atlantic Ocean. As part of this effort two physical oceanography cruises have been planned to collect full depth continuous conductivity, temperature, dissolved oxygen and pressure (CTD) profiles and nutrient data in conjunction with surface water samples and expendable bathythermographs (XBT). These cruises will tentatively be carried out in 1985-86 from the research vessel ARA PUERTO DESEADO.

The first cruise (Figure 1) is aimed to obtain a detailed hydrographic sampling of the southern continental shelf. As part of this program a zonal hydrographic section from the 200 m isobath to the Maurice Ewing Bank is planned. These measurements are designed to obtain a detailed density section across the most direct route for Upper Circumpolar Deep Water into the Argentine Basin.

The second cruise (Figure 2) will cover the region of the Subtropical Convergence and is aimed to obtain five sections across the western boundary currents of subtropical and subantarctic origin. Closely spaced (~30 km) CTD sections are planned in the region of the continental slope and where large horizontal property gradients occur.



65°
60°
55°
50°
45°
40°
35°
40°
45°
50°
55°
60°
ARGENTINA
100 bz
1000 bz
2000 bz
1000bz

Figure 1.

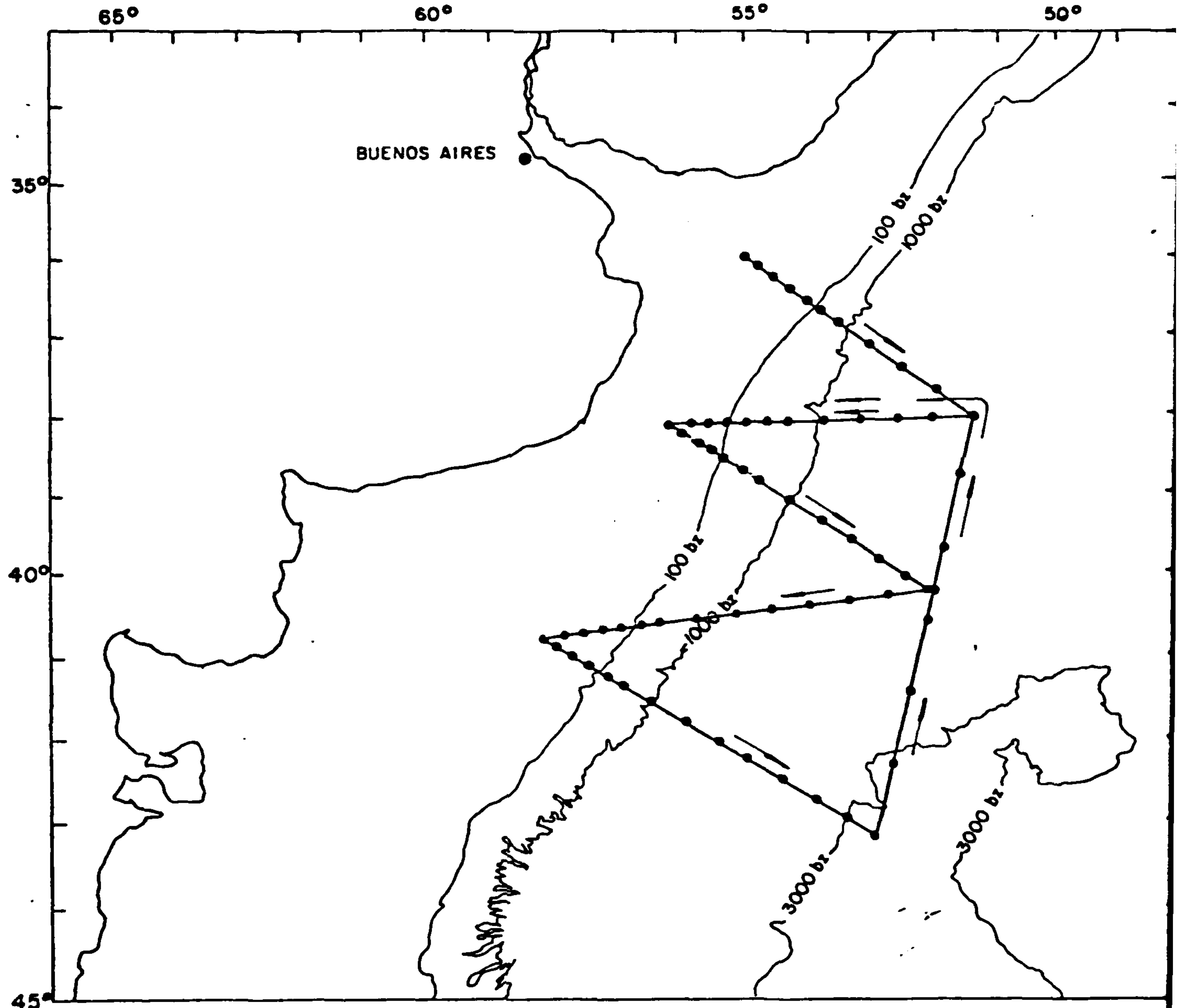


Figure 2.

BRAZIL

SUMMARY OF THE BRAZILIAN OCEANOGRAPHIC PROGRAMMES FOR THE SOUTH ATLANTIC

A. R. DE MESQUITA

IOUSP - SÃO PAULO - BRAZIL

FEBRUARY - 1983

SUMMARY OF THE BRAZILIAN OCEANOGRAPHIC PROGRAMMES FOR THE SOUTH ATLANTIC

This summary has been prepared for the Lamont Doherty Geological Observatory meeting on the oceanography of the South Atlantic and Indian Oceans during the days of 22 to 23 of February of 1983.

Only the large scale oceanic programmes have been summarized and are listed with the relevant information as follows:

1- PROJECT - Brazil Current

OBJECTIVE - Measurements of currents
XBT measurements
T & S measurements of the Southern branch of the Brazil Current.

AREA - Eastern part of the brazilian coast within 5° S to 21° S

PERIOD - 1983 - 1984

EQUIPMENT - Currentmeters + Pegasus + XBTs.

VESSEL - N/Oc. Prof. W. Besnard

RESEARCH AIMS - Calculation of the meridional heat flux of the Brazil Current

STATUS - Programme in course

PRINCIPAL SCIENTISTS - S. R. Signorini and A. da S. Mascarenhas

INTERNATIONAL LINKS - Programme in collaboration with the Woods Hole Oceanographic Institution USA + Univ.of Rhode Island, USA.

SUPORTING INSTITUTION - Instituto Oceanográfico da Universidade de São Paulo, CP 9075, São Paulo - Brazil.

2- PROJECT - PAVASAS - Amphidromic Points and Seasonal Variation of the South Atlantic

OBJECTIVE - Measurements of currents, T and S and Tides in chosen areas of the South Atlantic

AREA - South Atlantic

PERIOD - 1983 - 1988

EQUIPMENT - STD, NANSEN, Currentmeters and shelf water Tide Gauges

DATA REQUIRED - Satellite Altimetry Data for the South Atlantic

VESSEL - N/Oc. Prof. W. Besnard

REQUIREMENTS - International Cooperation is required for sea work measurements at areas near the African Continent; Patagonian shelf and Antarctic

RESEARCH AIMS - Model the South Atlantic
Studies on the mean sea level
Seasonal variability of currents T and S

STATUS - Funded for the 1st year

PRINCIPAL SCIENTISTS - A. R. de Mesquita - L. B. de Miranda - Y. Ikeda and A. S. Franco

SUPORTING INSTITUTIONS - 1) Instituto Oceanográfico da Universidade de São Paulo, CP 9075, S . Paulo - Brazil; 2) Instituto de Pesquisas Tecnológicas, Cidade Universitária, Butantã, S. Paulo Brazil.

INTERNATIONAL LINKS - Institute of Oceanographic Sciences, Bidston, Birkenhead, UK, + FOCAL + SEQUAL.

3- PROJECT - Oceanography of the Tropical S. Atlantic

OBJECTIVE - Analysis of data of S. Peter's rocks, Fernando de Noronha and Trindade Meteorological Stations + SST and Sea temperature at 20 m depth.
Analysis of the Infrared - 20° S - 10° N; data of GOES + TIROS SATELLITES

AREA - 10° N - 20° S - South Atlantic

RESEARCH AIMS - Contribute to the climatology of the South Atlantic, with emphasis in the North Eastern part of Brazil

STATUS - Funded for two years

PRINCIPAL SCIENTISTS - A. D. Moura, M. Stevenson, A. da S. Mascarenhas

SUPORTING INSTITUTION - Instituto de Pesquisas Espaciais, CP. 515, 12.200 - São José dos Campos- Est. de São Paulo, Brazil

INTERNATIONAL LINKS - SEQUAL and FOCAL

4- PROJECT - Oceanic Remote Sensing

OBJECTIVE - Studies of the Cabo Frio upwelling (23° S; 42° W) and the Sub-Tropical Convergence Zone 35° S to 40° S

AREA - Coast of Brazil 23° S - 42° W and band of 35° S to 40° S of the South Atlantic

PERIOD - 1983 - 1984

EQUIPMENT - NANSEN + CURRENTMETERS

DATA REQUIREMENTS - Oceanic Historical data plus Satellite Infrared data

RESEARCH VESSEL - N/Oc. Alte. Saldanha

STATUS - Funded for two years

PRINCIPAL SCIENTISTS - M. Stevenson, T. Keiko and H. Inostrosa

SUPORTING INSTITUTION - 1) Instituto de Pesquisas Espaciais, CP 515, São José dos Campos, S. Paulo, Brazil; 2) Diretoria de Hidrografia e Navegação, Ilha Fiscal, 20.000, Rio de Janeiro, Brazil.

5- PROJECT - CENTRATLAN

OBJECTIVE - Measurements of sea Magnetism, Sysmic, Gravity, Altimetry and Bathymetry of the S. Atlantic

AREA - South Atlantic

EQUIPMENT - Magnetometer, Sysmographer, Gravimeter, PDR, and Altimeter

RESEARCH AIMS - Geophysical work (mapping of the S. Atlantic)

DATA REQUIREMENT - Historical data produced by the Programme on Geology and Marine Geophysics (PGGM)

RESEARCH VESSELS - N/Oc. Alte. Câmara + AIRCRAFT

STATUS - Funded for two years

PRINCIPAL SCIENTISTS - M. A. Gorini, J. Palma

SUPORTING INSTITUTIONS - 1) Diretoria de Hidrografia e Navegação, Ilha Fiscal, 20.000, Rio de Janeiro, Brazil; 2) LAGEMAR, Universidade Federal do Rio de Janeiro, Bloco A/CCS/UFRJ/Rio de Janeiro, 21.910 - Ilha do Fundão, Rio de Janeiro, Brazil

INTERNATIONAL LINKS - The Programme is funded by the Brazilian and US Navies

NOTE: This information has been taken from the - 1º Plano Bá sico Setorial para os Recursos do Mar (1º PSRM) - prepared by CIRM - Comissão Interministerial para os Re - cursos do Mar (Interministerial Committee for Sea Resources) - Address: Esplanada dos Ministérios, Ministé rio da Marinha, 4º andar, 70.000 - Brasília - DF, Brazil. Attention: CMG E.G. de Almeida. Few copies of the the full programme are available.

F. G. R.

ONR-Conference "Research Program in the South Atlantic and Indian Oceans"

at Lamont on 22 and 23 February 1983.

Conceivable contributions from the Federal Republic of Germany

by

W. Zenk, Institut für Meereskunde, Kiel, F.R. Germany

Introduction

A historic contribution to the physical exploration of the South Atlantic Ocean was delivered by pre-war Germany. The importance of a series of systematic zonal sections, conducted by "Meteor" during the "Deutsche Atlantische Expedition" 1925-27, recently has been rediscovered with the general tendency to large scale phenomena in oceanography. Because of their significance A. Defant's and G. Wüst's main contributions on the troposphere and the stratosphere of the Atlantic recently were translated into English (by W.B. Emery). These useful works enable now a larger scientific community to incorporate these fundamentals into their ongoing own work. As in the U.S. also in the Federal Republic of Germany a renaissance of classical hydrography on larger scales took place with the foundation of a joint research project (SFB) at Kiel University in 1980. It is called "Warmwassersphäre des Atlantiks" and it aims at the clarifications of meridional heat transport processes and the recirculation problem of the North Atlantic. In spite of the title, covering the whole Atlantic, so far all SFB experiments have been conducted in subtropical and subpolar regions of the North Atlantic. On the other hand there exist some moderate research projects on South Atlantic hydrography in Germany, which might be intensified without too much additional efforts. I am not aware of any ongoing activity in our country in the South Indic.

Up to now activities in the South Atlantic Field observations

Nearly all work is connected with Antarctic supply ships being used as ships of opportunity. The work concentrates on the collection of consistent surface and XBT data sets. We in Kiel have conducted repeatedly (since 1978) megameter long XBT sections between the Bay of Biscay and South Africa/South American, respectively (cf. Fig. 1). While in the beginning only a descriptive interpretation of the thermal structure of the warm water sphere was possible, we now think that we can approach a more statistical analysis of the observations (cf. Tab. 1).

While this conference is under progress two ships continue the completion of eastern basin XBT data. According to the current cruise plan the mission of the new ice breaking research and supply vessel "Polarstern" includes:

- continuous registration of surface temperature and salinity
- XBT sections and radio sonde ascents between 40°N and 70°S
- "Sea Beem" echosounding with computer supported on-line analysis of the bottom topography.

On her return leg to Bremerhaven, also the supply ship "Polarbjörn" is supposed to conducted highly resolving temperature and salinity sampling at the sea surface. Thus work aims at the repeated observations of open ocean fronts.

Modeling efforts

The Institut für Meereskunde at Hamburg University recently has expressed his interest to start a wind generated thermohaline circulation model of the South Atlantic, south of 30°S between 70°W and 20°E. The model will contain 10 layers. It is supposed to be coupled later with an existing circulation model of the Atlantic ocean north of 30° S. The project is directed by Prof. J. Sündermann, head of IfM Hamburg.

Some issues partly under investigation

- How comperable are northern and southern temperature structures of the warm water sphere?
- Which influence has the Mediterranean Outflow on the extend of the warm water sphere?
- Are eddy frequency and size a function of latitude?
- What are characteristic surface and subsurface indicators of fronts separating different circulation regimes?
- Which climatic pattern governs the migration of thermohaline surface frontal structures and heat content variations?
- Which longer term variations occur in the equatorial circulation system?
- How does the bottom topography of the deep sea interact with the warm water sphere?

Possible intensification of oceanographic research in the South Atlantic

Also in the future all studies in the South Atlantic will be conducted on supply and research cruises towards "Georg-von-Neumeyer" (71°S, 8°W) at Atka Iceport, Antarctica. It is unnecessary to say, that routes are restricted by the primary missions of the ship(s). Only minor deviations from direct track lines towards the Rio de la Plata or towards Cape Town and from there to "Georg-von-Neumeyer" are feasible. However, within these limits every rapid underway sampling technique could be operated on the new ice breaking research and supply vessel "Polarstern" twice per year. The conceivable spectrum of scientific missions could include

- "Sea Beam" surveys
- XBT sections (later XCTD sections)
- radio sonde ascents
- diverse air chemistry profiles
- GEK and magnetometer tracks
- XCP profile series
- collection of numerous surface parameters
- and rapid launching of dirifting buoys.

"Polarstern" is operated by Alfed-Wegner-Institut für Polarforschung, Bremerhaven, headed by Prof. G. Hempel.

Table 1 – The locations of observed features during different sections across the Atlantic

Zone	feature	W March 81	K Dec 80	Henke and Zenk March 80	Henke Juli/Aug 78	Becker et al Begin of Oct 80	Becker et al End of Oct 80	Bruckmann et al Feb – Jun 79	Huber et al Juli/Aug 74
1	location and depth of Mediterranean outflow water	northward 35° N >650 m	northward 34° N >650 m	northward 37° N >650 m	*)	*)	*)	*)	*)
2	location of the 15 °C isotherm drop (1)	33.5° N, 18° W (Madeira) 36.5° N, 15.5° W (Josephine-seam.)	34.5° N, 13.5° W (Seine-seamount)	34.5° N, 13.5° W (Seine-seam.) 36.5° N, 12° W Gettysburg-seam.)	36.5° N, 12.5° W (Gettysburg-seamount)		34° N, 15° W (Seine-seamount)	*)	*)
2	max. depth of 15 °C isotherm (Center of the subtropical convergence)	29° N 310 m	26° N 300 m	31° N 280 m	30° N 280 m	25° N 280 m	25° N 110 m	*)	24° N 360 m
2–4	region and depth of the max. vertical temperature gradient	15° S to 15° N *20 to 60 m*	6° S to 10° N *50 to 110 m*	20° S to 10° N *15 to 70 m*	20° S to 20° N *20 to 100 m*	7° S to 14° N 40 to 100 m	7° S to 14° N 40 to 100 m	6° S to *) 30 to 100 m	*) to 12° N 30 to 100 m
3	*minimal mixed* layer depth (north equatorial divergence zone)	8.5° N 10 m	12.5° N 40 m	8° N 5 m	10° N 10 m	11° N 30 m	13° N 30 m	8° N 20 m (2)	6.5° N 20 m
3	mixed layer depth at the equator	20 m	80 m	20 m	20 m	90 m	60 m	(7) 50 m	40 m
3	thermal equator (maximal sea surface temperature)	5.5° N >29 °C	4.5° N >27.5 °C	3° N >28.5 °C	13° to 15° N >28 °C	0° N >28 °C	5° N >28 °C	*) >28 °C	4.5° N >26 °C
3	thermostad	4° S to 3° N 13 to 15 °C	4° S to 4° N 11 to 13 °C	4° S to 4° N 13 to 15 °C	4° S to 3° N 13 to 15 °C	4° S to 0° N 11 to 13 °C	5° S to 7° N 11 to 14 °C	4° S to 6° N 12 to 14 °C	(3) 5° S to 4° N 12 to 14 °C
3	NEC (north equatorial current)	9° to 12° N	12.5° to 18° N	8° N to *)	10° to 16° N	12° to 22° N	12° to 22° N	*)	7° to 12° N
3	NECC (6) (north equatorial countercurrent)	3° to 8° N	5° to 10.5° N	4° to 8° N	5° to 10° N	3° to 12° N	3° to 12° N	5° to 9° N	4° to 7° N
3	NEUC (north equatorial undercurrent)		4° N ~250 m			7° N ~250 m	6° N 250 m		2° to 4° N ~300 m (4)
3	EUC (equatorial undercurrent)	0.5° S to 0.5° N 80 m	1° S to 1° N 130 m	0.5° S to 0.5° N 90 m	km south of the equator 50 m	1° S to 0° 150 m	0° to 1° N 130 m	0.5° S to 0.5° N (7) 100 m	1° S to 0° 100 m
3	SEUC (south equatorial undercurrent)	4° to 3° S ~200 m	4° to 3° S ~200 m	4° to 2° S ~230 m	4° to 2° S ~200 m	4° to 3° S ~200 m	4° to 3° S ~200 m	4° to 1° S ~250 m	(3) 5° to 2° S (5) ~300 m
3	SEC (south equatorial current)	7° S to 2° N	6° S to 2° S	6° S to 1° N	8° S to 2° N	14° S to 6° S	14° S to 3° N	6° S to *)	(3) 5° S to 4° N

notes: *) no measurements in that depth or region

[ ] this feature was not observed

(1) The 15 °C isotherm drop is next to the following seamount
(2) This section ends at 8° N
(3) This section ends at 5° S
(4) Called by Huber et al. subthermocline North Equatorial Counter Current
(5) Called by Huber et al. northern edge of the South Equatorial Counter Current
(6) Also called Equatorial Counter Current in older literature
(7) This depth measured with a CTD instrument was given by E. Fahrbach in a personal communication

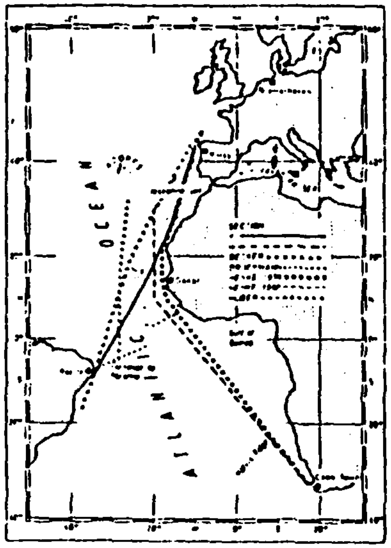
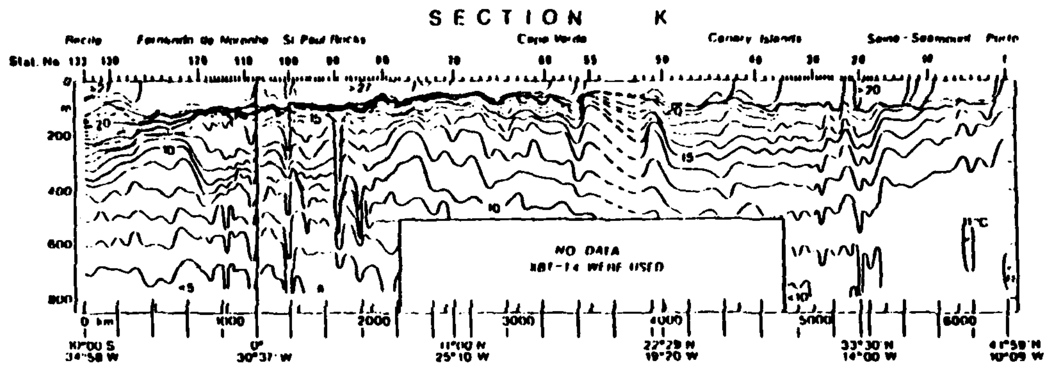
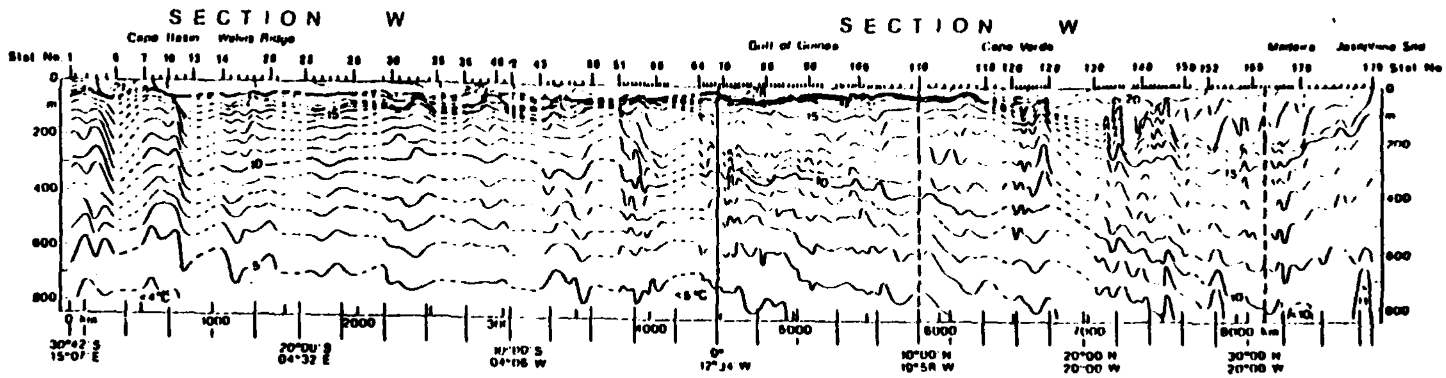


Fig. 1 Track lines of selected XBT sections across the Atlantic Ocean (Sections K and W are shown in Fig. 2 and 3)





FRANCE

Gilles Reverdin

Abstract of the French program in the Southern Indian Ocean (excluding ice studies).

Scientific Objective: Study of the circumpolar current with specific emphasis on seasonal and interannual variability.

Logistics

1. This program relies heavily on satellite techniques: altimetry (POSEIDON-SPOT 2); scatterometer (ERS1); thermography and sea color (Japanese satellite).

2. Marion Dufresne, a vessel of the TAAF going twice a year to the French Islands of the Southern Indian Ocean: Amsterdam (75E; 40S), Crozet (50E; 48S), Kerguelen (70E; 50S), La Réunion (56E; 22S).

3. A small vessel going to Terre Adelie during the Southern hemisphere summer.

Field Experiments

1. 10 deep ocean tide gauges and carefully calibrated tide gauges in shallow waters near the islands (tide models obviously needed for POSEIDON altimeter, ground truth for time variations on seasonal or interannual time series).

2. Hydrological data as well as geochemical data sampled along ship tracks especially between Kerguelen and Crozet.

3. Drifting buoys launched in the circumpolar current.

Laboratories Involved

LOP - Museum (Paris; general circulation models), IMG (Grenoble; tides), IPG and IPC (Paris; geochemical tracers), GRGS (Toulouse; altimetric data), EERM (Brest; drifters).

The bulk of this program should take place with satellites after 1986?

French Interests in the Equatorial Indian Ocean

- Scientific objectives:

    1. Roots of the equatorial undercurrent (west of 57°E) and its temporal variability.
    2. Studies of the Somali current, in the late monsoon (from end of July through September). Conditions needed for its extension to the North along the coast.

- Logistics

    1. Marion Dufresne cruises from Marseille to La Réunion Island.
    2. Small vessel in Seychelles Islands.

- It could include some moorings as well as drifting buoys.
- It could not take place before the end of 1984.

SOUTH AFRICA

ONR Meeting on Southern Ocean Research Programme

Some thoughts on research priorities

Lutjeharms

(1) The East Madagascar Current and the currents in the Mozambique Channel are torally undersampled or even non-sampled, of crucial importance in understanding the interrelationships between all circulation elements in the southwest Indian Ocean and are, for political reasons, inaccessible to countries with deep-sea research capability in the region. From a theoretical point of view the shielding of the western boundary by Madagascar is interesting. The East Madagascar, a well-developed miniature western boundary current, can be considered a boundary current laboratory: it is small enough to be rapidly sampled, it is readily accessible from Mauritius and may be monitored by only a few tide gauges along the Madagascar coast.

(2) The Brazil/Falkland Current Confluence has been investigated in a modern fashion only once. It has been demonstrated that the area is one of very high variability, of unusual western boundary behavior and is amenable to satellite infrared imagery. The probability of significant research efforts being generated from countries in the region are small. A combination of extensive hydrographic cruises and drifting buoys will give information required to understand the region as well as to understand western boundary currents as a whole.

(3) The central area of the South Atlantic is undersampled and in many respects terra incognita. The location, nature and behavior of the Subtropical Convergence and the exchange of water masses between the Subantarctic and Subtropical regions. The latter is important to an understanding of the meridional heat and salt flux. The possibility of a South Atlantic El Niño has been mooted and is, to a limited extent being addressed by SEQUAL, but no work further south is at present to my knowledge being considered.

(4) The spread of bottom water from the Weddell Sea into the Atlantic and Indian Oceans is at present to a large extent surmised from the distribution of bottom water parameters based on combining the total available data set. Well-placed sections of stations to the ocean bottom, particularly adjacent to ridges where bottom boundary currents may be expected, could go far towards establishing the main pathways of bottom water penetration into the Atlantic and Indian Oceans.

(5) The southern part of the Agulhas Current has been demonstrated to be an area of extremely high variability and horizontal contrasts. It has been, and is being studied by means of XBT sections, satellite remote sensing and drifting buoys. A well-focused, integrated cruise in the area seems to be the next logical step to increasing our understanding. A cruise using real-time satellite imagery and concurrent drifter deployments in combination with hydrographic stations would seem to be the ideal.

J. R. E. Lutjeharms
1983-02-23

SOUTH ATLANTIC OCEAN HEAT TRANSPORT

Notes Prepared for the ONR Sponsored Southern Ocean Research Meeting

Lamont-Doherty Geological Observatory, February 1983

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February 1983

The purpose of this note is to show why calculations of heat transport in the South Atlantic yield equatorward heat transport, to show the similarity between mid-ocean flows in the South Atlantic and North Atlantic, and to emphasize the need for direct velocity measurements of the Brazil Current.

Current opinion is that the ocean heat transport in the South Atlantic is directed equatorward. According to Stommel (1980), it is the only ocean basin with equatorward heat transport at a latitude of 25°. This is a surprising result†, so surprising that Wüst apparently left out his heat transport calculations from the comprehensive summary of South Atlantic circulation determined from Meteor measurements (Wüst, 1957). In the last 20 years, numerous investigators have estimated South Atlantic heat transport to be equatorward both from Meteor and IGY (Fuglister, 1960) measurements and the values at 24°S, for example, have varied only from 0.3 to 0.6 $\times 10^{15}$W (Bryan, 1962; Bennett, 1978; Fu, 1981; Roemmich, 1983). With the safety of such similar heat transport values, it is now fashionable to conclude that the South Atlantic does indeed transport heat poleward.

It is relatively easy to understand why these calculations yield equatorward heat transport. Using 2 hydrographic stations in deep water on the eastern and western sides of the South Atlantic at 24°S one can estimate the average mid-ocean geostrophic velocity profile (Figure 1). While such profiles are not reliable for determining deep water flows because topographically confined flows are not included, they are usually

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† Bruce Warren insists that his calculation of equatorward heat transport in the South Atlantic for a homework exercise in Victor Starr's course in 1959 did not surprise him at all because property transports in Victor Starr's course always went the wrong way.

good indicators of upper water flows. In this profile for 24°S, there is clearly an equatorward flow of upper, warmer water just as one expects for Sverdrup flow in a subtropical gyre. In fact, the equatorward Sverdrup transport, $\frac{\nabla \times \tau}{\beta} \Delta x$, of 17.5 Sv between these 2 stations agrees reasonably well with the equatorward geostrophic transport of upper water relative to 1000 m, $\int_{-1000}^{0} (v - v_{1000})\, dz\, \Delta x$, of 20.3 Sv. Because there is little baroclinic evidence of a western boundary current against Brazil in the 24°S section, the heat transport calculations return this mid-ocean equatorward flow of upper water as a poleward flow of colder, deeper water. The result is a strong equatorward heat transport in the South Atlantic.

Compare this situation with the circulation at 24°N in the North Atlantic, where the heat transport is strongly poleward (Bryden and Hall, 1980; Roemmich, 1980; Wunsch, 1980). Using 2 hydrographic stations on the eastern and western sides of the North Atlantic at 24°N, one estimates a mid-ocean geostrophic velocity profile (Figure 2) which is similar to the one for the South Atlantic at least in the upper water. Again there is an equatorward geostrophic transport of upper water relative to 1000 m of 16.4 Sv in good agreement with equatorward Sverdrup transport of 17.3 Sv.

(Δx is much bigger)

But in the North Atlantic, the mid-ocean equatorward transport in the upper water is more than compensated by the poleward Gulf Stream flow through Florida Straits so there is a net poleward flow of warmer, upper water across 24°N which is compensated by an equatorward flow of colder, deeper water. The result is a strong poleward heat transport across 24°N. It is worth noting that, if one were not aware of the Gulf Stream flow

a barocli flow

through Florida Straits and calculated heat transport only for the mid-ocean region between the Bahamas and Africa, one would calculate an equatorward heat transport of 0.4×10^{15}W across 24°N (Hall and Bryden, 1982) much like the South Atlantic values.

Thus, the mid-ocean upper water circulations in the South and North Atlantic are similar and approximately what is expected for Sverdrup flow in the respective subtropical gyres. What is different about the South and North Atlantic is the presence of a strong western boundary current in the North but a weak or absent western boundary current in the South.

How sure are we that the Brazil Current is small in the South Atlantic? There is little baroclinic evidence, that is strongly sloping isotherms against the western boundary, in the IGY sections at 16°, 24°, and 32°S. Gordon's (1980) hydrographic sections south of 38°S do show a baroclinic signal of a Brazil Current. The Brazil Current, however, could be nearly depth independent north of 35°S and hence have little baroclinic signal. Direct velocity measurements would then be needed to measure the Current. For this reason, we recommend that some direct velocity measurements be made within 100 km of the Brazil, Uruguay or Argentina coasts to look for evidence of a depth-independent Brazil Current. Moored time series measurements are preferable to establish the temporal and vertical scales of variability. It may be possible to use the synoptic Pegasus velocity sections planned by Evans and Stommel for a cruise in Spring 1983 to choose an optimal site for such moored measurements. We tentatively envision an initial small program of 2 moorings, each with 4 current meters at about 50 km from the coast in about 1000 m water depth: one at 24°S to complement the IGY hydrographic section and one at 35°S where the maximum wind stress curl occurs. If evidence of a Brazil Current were found, a somewhat larger program could be planned to measure the transport of the Brazil Current.

If there is indeed a significant Brazil Current in the South Atlantic, it would change our concepts of South Atlantic circulation and heat transport. If there is no significant Brazil Current, we are left with the problem of understanding how the vorticity put into the South Atlantic by the wind stress curl is balanced without a western boundary current to provide frictional dissipation. In either case, we need to determine whether or not there is a Brazil Current.

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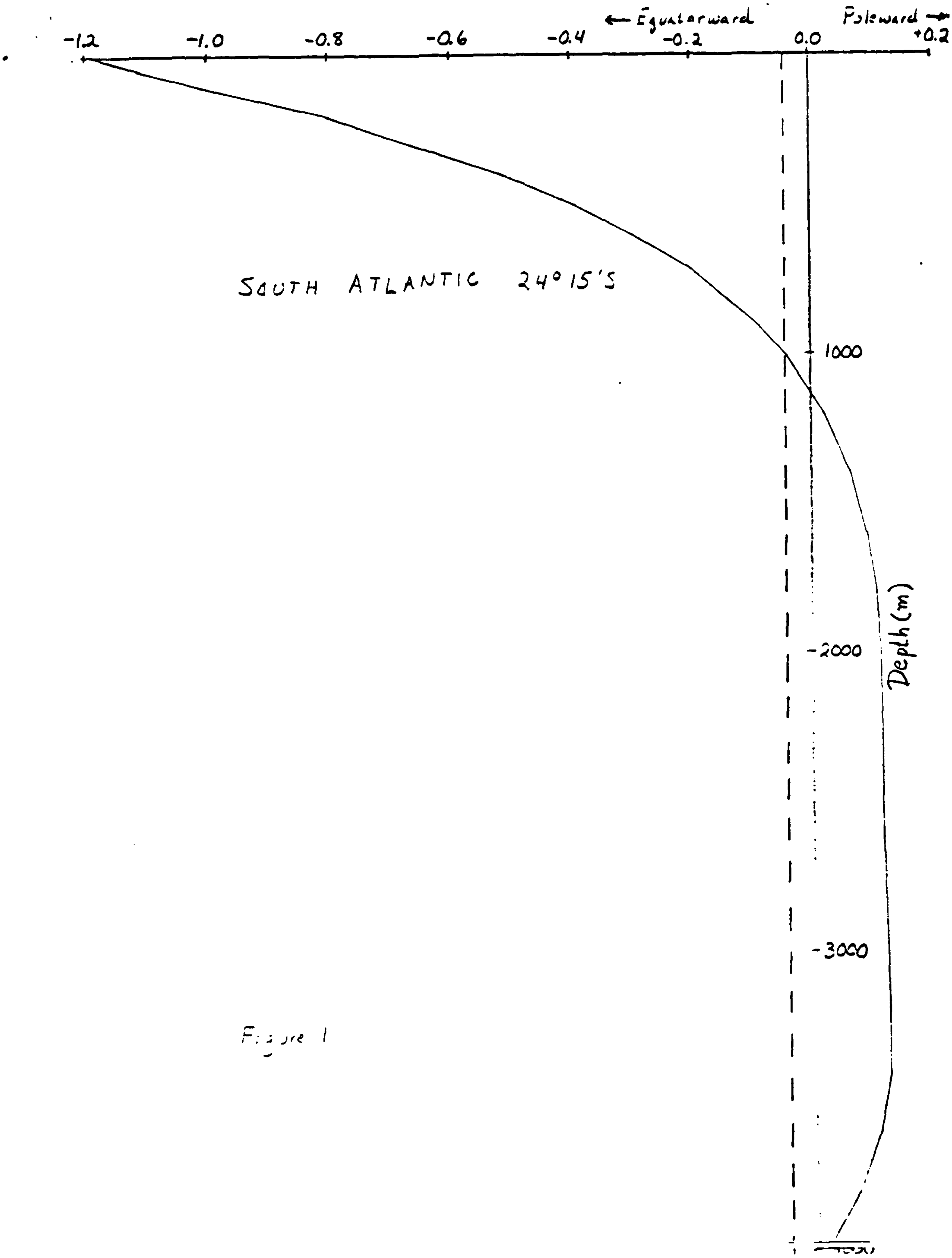
FIGURE CAPTIONS

Figure 1. Mid-ocean geostrophic velocity profile at 24° South Atlantic. Hydrographic stations used ar at 24° 15'S, 9° 46'E and *Crawford* 22-421 at 24 (Fuglister, 1960). Geostrophic velocity is re 4065 m. To make a baroclinic profile with no barotropic velocity of + .045 cm s^{-1}, shown vertical line, should be added to this relativ The transport per unit width in the upper wate $\int_{-1000}^{0} (v - v_{1000})\, dz = -4.51\ m^2\ s^{-1}$, agrees r with the Sverdrup transport, $\frac{\nabla \times \tau}{\beta} = -3.69 \times$ estimated from wind stress curl values given b Veronis (1975).

Figure 2. Mid-ocean geostrophic velocity profile at 24° North Atlantic. Hydrographic stations used ar at 24° 36'N, 20° 50'W and *Discovery* 3623 at 24 (Fuglister, 1960). Geostrophic velocity is re To make a baroclinic profile with no net trans velocity of -.027 cm s^{-1}, shown by the dashed should be added to this relative profile. The unit width in the upper water, $\int_{-1000}^{0} (v - v_{1($ $-3.00\ m^2\ s^{-1}$, is in good agreement with the S port, $\frac{\nabla \times \tau}{\beta} = -3.17\ m^2\ s^{-1}$, estimated from w values given by Evenson and Veronis (1975).



← Equatorward
Poleward →
-1.2
-1.0
-0.8
-0.6
-0.4
-0.2
0.0
+0.2
SOUTH ATLANTIC 24° 15'S
1000
-2000
-3000
Depth (m)

Figure 1

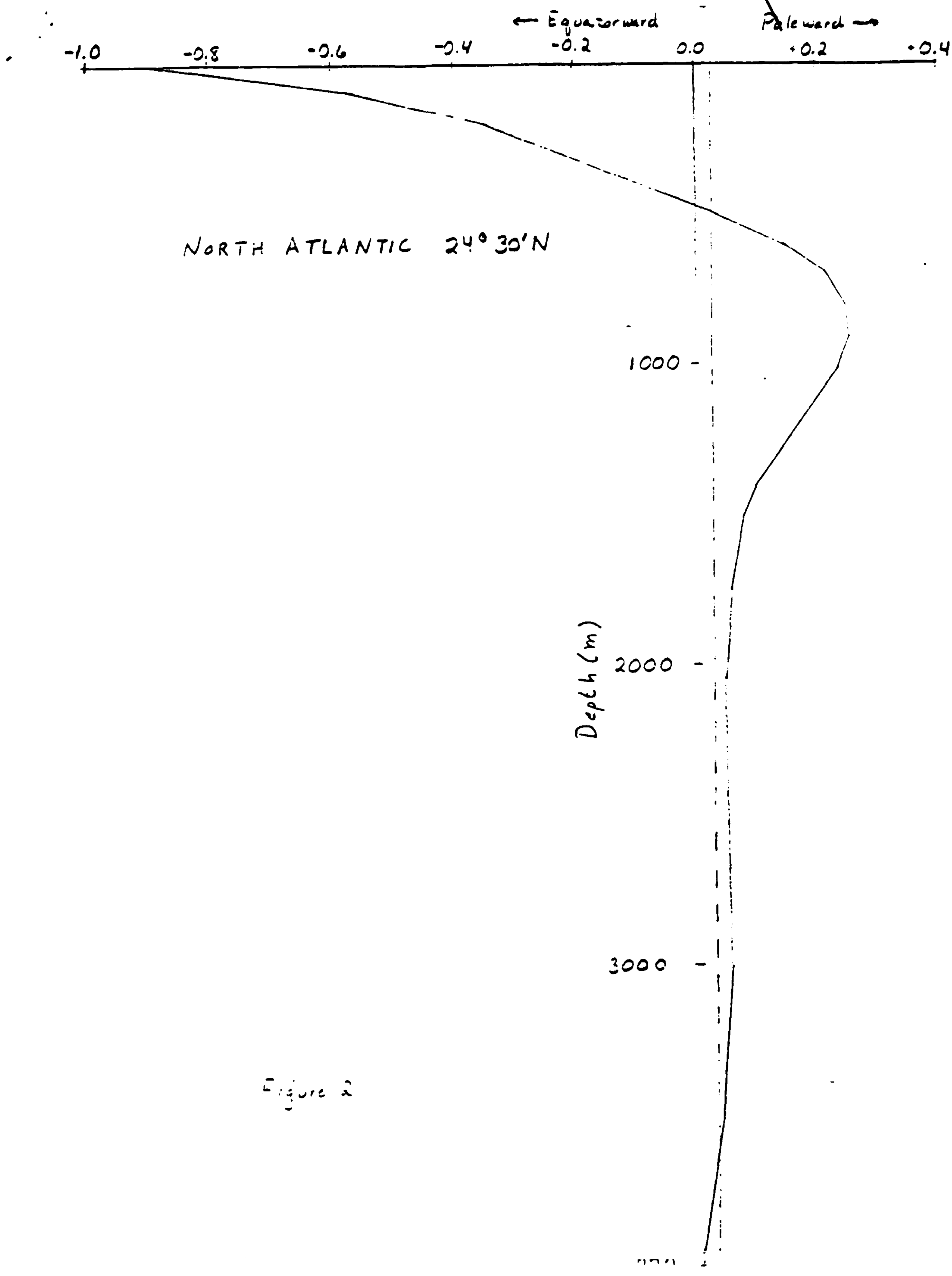

← Equatorward
Poleward →
-1.0
-0.8
-0.6
-0.4
-0.2
0.0
+0.2
+0.4
NORTH ATLANTIC 24° 30'N
1000
2000
3000
Depth (m)

Figure 2

Holland

Questions Addressable By Models

(1) What is the nature of non-Sverdrupian (intense) interior currents? Do they exist? Are they unstable?

(2) What is the nature and interrelationship of eddy and mean circulations in the Agulhas retroflection region?

(3) Does eddy variability propagate westward from the tip of South Africa? If so, what role does it play in mixing properties?

(4) Does the eastern boundary current of the South Atlantic (Benguela Current) play any essential role in the transport picture?

(5) Is there any important connection between the Circumpolar Current and the mid-latitude gyres?

(6) What is the structure and penetration of the Brazil Current eastward? What is the nature of the eddy/mean flow interactions there? What deep mean current patterns (Worthington-like gyres) result? Are these similar or different from the North Atlantic?

(7) Does the reverse slant of the western boundary in the South Atlantic affect the separation of the Brazil Current?

(8) Is thermocline ventilation different because of different geometry and different outcrop regions? Do the South Indian and South Atlantic "interconnect" along some density surfaces?

(9) What does the strong seasonal signal do to the Agulhas Current (Cox focused upon the Somali Current region)? What are the winds like along the African coast south of the Equator?

Transient Tracers in the Ocean

Ten Year Plan
September 1982

Transient Tracers in the Ocean

Ten Year Plan:

Executive Summary

The oceans are important both in global climate and in the uptake of man-made substances - particularly the potential climate modifier CO_2. Prediction of future changes requires quantitative understanding of the physico-chemical dynamics of the oceans, and we propose to aid in the achievement of this goal by measurement of transient (man-made, time varying) tracers in the ocean. The major thrust of the program is to obtain a series of "snapshots" of the distribution of several of these substances and use their differing natures, time histories, and boundary conditions to help unravel the complex oceanic processes responsible. These snapshots will be achieved by a series of regional scale surveys which, when combined, will map the entire world ocean during the next decade. Complementary to this we propose more spatially concentrated "process" studies as well as timeseries measurements. To achieve this we require and strongly urge the continued support of the Physical and Chemical Oceanographic Data Facility located at Scripps Institution of Oceanography. Modelling and interpretation will proceed on the basis of both simple "analog" models and the more complex diagnostic calculations. A large scale prognostic model is the ultimate goal.

The overall program is managed by a steering group of five scientists, and the regional-scale sub-units of the program will be organized by a specific scientific executive committee.

Transient Tracers in the Ocean

Ten Year Plan

1. Rationale

Over the past decade man has become aware of the possibility that his activities may lead to major alterations in global climate. Much of this concern has focused on the buildup of fossil-fuel CO_2 and other "greenhouse" gases in the atmosphere. Efforts to evaluate the impact of these changes on sea level, on agricultural productivity, and on natural ecosystems have led to the realization that our lack of understanding of transports within the sea and interactions between the sea and atmosphere introduce considerable uncertainty into the impact projections. The sea is the primary sink for the CO_2 being added to the atmosphere through the burning of fossil fuels, as well as being an important heat buffer which will delay the warming produced by the buildup of this CO_2 in the atmosphere. But ocean circulation and mixing are sensitive to climatic change, so one of the first order tasks in evaluating the coming changes must be to obtain a better understanding of the dynamics of the sea. We must push as rapidly as possible the development of atmospheric coupled general circulation models for the sea akin to those now employed in atmospheric research. This is no simple task. It will require at least a decade of effort by the best minds in ocean science.

As with carbon dioxide, our understanding of the role of the sea in modulating the composition of the atmosphere is dependent both on the physics and chemistry of air-sea exchange, and on the dynamics of ocean circulation and mixing. The oceans play a significant role in the global transport of heat as

The observations of tritium, ^{3}He and ^{14}C made during the GEOSECS expedition in the 1970's provided us with a first picture of the pathways by which these substances invade the oceans. Coupled with later, more regionally concentrated observations and the Transient Tracer survey in 1981, we see the time evolution of these important tracers. The imprint of the global scale thermohaline circulation, the intense boundary currents and the wind driven gyres on the transport and dispersion of these tracers is sharply visible. Tritium and ^{14}C feel the deep convective activity in the northern regions, and the deep Western Boundary current is clearly labelled by both freons and tritium. The rapid homogenization of the wind driven gyre is evidenced by ^{3}H and the ^{3}He distribution.

The study of tracers on regional and global scales gives a kind of information not directly addressable by eulerian (current meter) measurements, and emphasizes broader scales and different boundary conditions from floats and drifters. The dispersive processes, i.e., stirring, mixing and diffusion are necessarily statistical by nature, and are not easily detectable by direct physical measurement. Horizontal flow in the oceans is generally strong and readily measured using current meters and Lagrangian floats; but the far smaller vertical flow which controls the dynamics of the wind driven gyres, and the global thermohaline circulation cannot be directly measured by such techniques. The different approaches, when eventually integrated, will ultimately provide a more complete understanding of the oceans.

The development and improvement of higher resolution and physically more realistic dynamical models requires not only the availability of sophisticated computers of the CRAY and CYBER class, but also the observations to test them and guide their evolution. A major challenge in the coming years is to develop the interface between the data and the models, and to establish a strong rapport between the theory, the numerical experiments and the observation programs.

2. History of Tracer Work

Prior to 1950 the only properties of sea water used to trace the flow paths of water through the interior of the sea were salinity and dissolved oxygen. Through the use of T-S diagrams physical oceanographers were able to define the major sources for intermediate and deep water. From the distribution of dissolved oxygen a first order impression of the relative ages of deep waters was achieved. While this classic work established the basis for subsequent studies of the ventilation of the sea it did not even scratch the surface of the information carried by the distributions of substances dissolved in the sea.

It was Libby's discovery of natural radiocarbon which launched a major interest in "tracer" oceanography. It was recognized that the distribution of this isotope held the key to the time scale of deep sea ventilation. Within a few years after the discovery of natural radiocarbon it was realized that through nuclear tests man was introducing tracers to the sea. Again geochemists were there to take advantage of the information available from this global "dye" experiment. With IGY in 1959 came the realization that the uptake of fossil fuel CO_2 by the sea was a subject meriting attention. This gave geochemists added incentive to understand the processes involved in the transport of carbon through the sea.

During the 1960's techniques were developed for measuring a host of tracers in the sea. Profiles were measured here and there allowing the main features of the distributions of these substances to be defined. However, little progress was made toward obtaining the kind of detailed three-dimensional information available for T, S, and O_2. Late in this decade Henry Stommel encouraged the geochemical community to band together and measure the distribution of radiocarbon along north-south sections in the three oceans. The bait was taken. In 1969 the GEOSECS program was born. During the 1970's not only radiocarbon but also many other chemical, isotopic, and radiochemical tracers were mapped on a global scale.

The GEOSECS tritium results dramatically demonstrated the value of transient tracers to our understanding of the ventilation of the main thermocline and of deep water renewal. However, full benefit from the information carried by the distributions of these substances could not be obtained from the GEOSECS data set alone. It was too sparse in key areas. More importantly, the temporal evolution of the tracer distribution gives more information than a single snapshot. To meet this need the Transient Tracers program was created. Thus far this program has conducted detailed measurements in the equatorial Pacific (part of the Hawaii-Tahiti shuttle study) and in the northern Atlantic (the first major TTO field program). In late 1982 the second major effort of this program, work in the equatorial Atlantic, will be conducted. As outlined in this document we propose to extend these surveys to other parts of the ocean.

3. Tracers

The tracers that must be measured include oxygen, uitrate-nitrite, phosphate, silicate and T-S-P, as well as a number of trace gases and the transient tracers. It is extremely important that a consistently high-quality set of data is collected at sea, and that samples for shore based analyses are taken and documented in a stringent and careful way.

The tracers we measure have different time histories, boundary conditions and *in situ* behaviours. Because, in a sense, they largely enter the ocean in the same general way (i.e. from the surface), their distributions will look qualitati ely similar. However, the differences in the distributions will reflect their different characters, and how the differences arise provides an important quantitative diagnostic of the transport processes occurring.

Tritium (half-life 12.5 y) occurs as part of the water molecule entered the hydrosphere as a spike-like injection in the early 1960's due to the atmospheric bomb tests, and was largely delivered to the northern hemisphere. The daughter of tritium, ^3He, provides sensitivity, shorter timescales, and is a strong indicator of mixing and back-flux to the atmosphere. Carbon-14 exists primarily as CO_2 in the atmosphere, although the timescale for ocean-atmosphere carbon isotopic exchange (more than a decade) greatly exceeds that of CO_2 gas exchange (1-2 years). We see a composite imprint of bomb production and fossil-fuel dilution on the natural background with the former at present dominating, a similar time history to tritium but more spread out and a more hemispherically symmetric delivery. The freons and ^{85}Kr have time histories qualitatively like anthropogenic CO_2, i.e. increasing in time, but at doubling times much shorter. They too have relatively uniform delivery.

^{39}Ar, although not a transient tracer, has a half life of slightly less than three hundred years, and is well suited to the timescales of the thermohaline circulation. Ra^{228}, issued from deep ocean sediments and continental rises, gives information on deep horizontal transport and mixing in the thermocline. Finally, the measurement of atmospheric and surface water gases (CO_2, CH_4, N_2O) coupled with ^{222}Rn provides valuable insight into gas exchange processes.

Figure 1 compares, in a schematic fashion, the time histories (Fig. 1a) and the spatial delivery patterns (Fig. 1b) of some of the transient tracers. The characteristic impulse shape of the tritium and its spatial asymmetry stand out. Each tracer contributes to our knowledge of processes occurring on differing timescales, and Figure 1c shows the relative contributions in a cartoon-like fashion.

Clearly it is important to measure not just one of the above tracers, but all of them, although not necessarily with the same frequency. Logistics and scientific rationale mediate our choice of how often to sample what tracer and where, and the rates can range from 30 Hz (the CTD), through 10^{-3} Hz (underway gas analyses), every water sample (salinity, oxygen, nutrients), to perhaps a few samples per leg (e.g. ^{39}Ar).

4. Facilities

A) Ships

The field work for this program can be executed in two ways. Some of the transient tracers, tritium, helium-3, and the freons, require rather small samples, of the order of a liter or less, and sampling for these can, in prin-

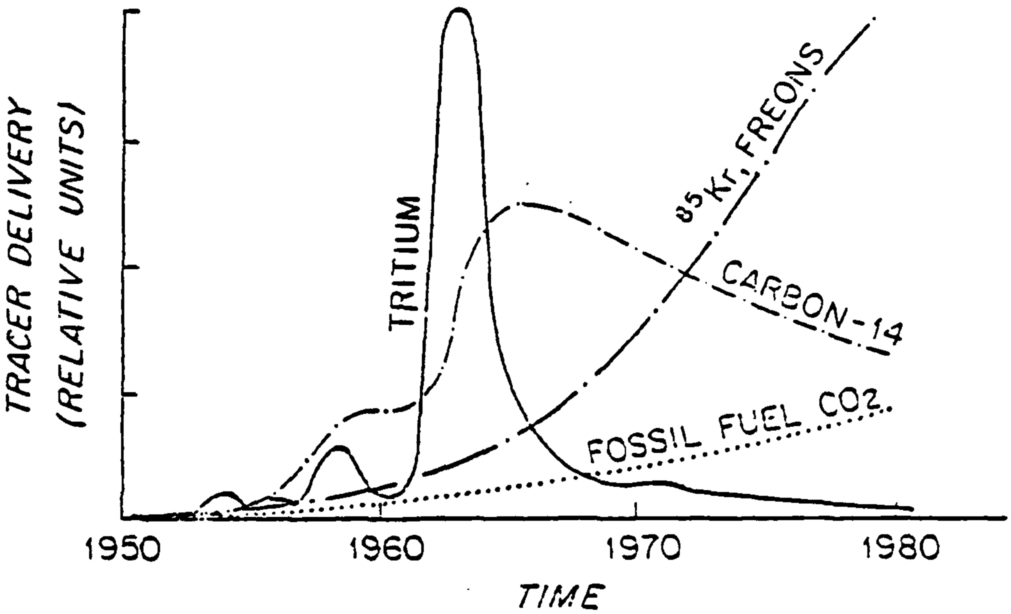


Figure 1a. Time histories of transient tracer delivery to the oceans.

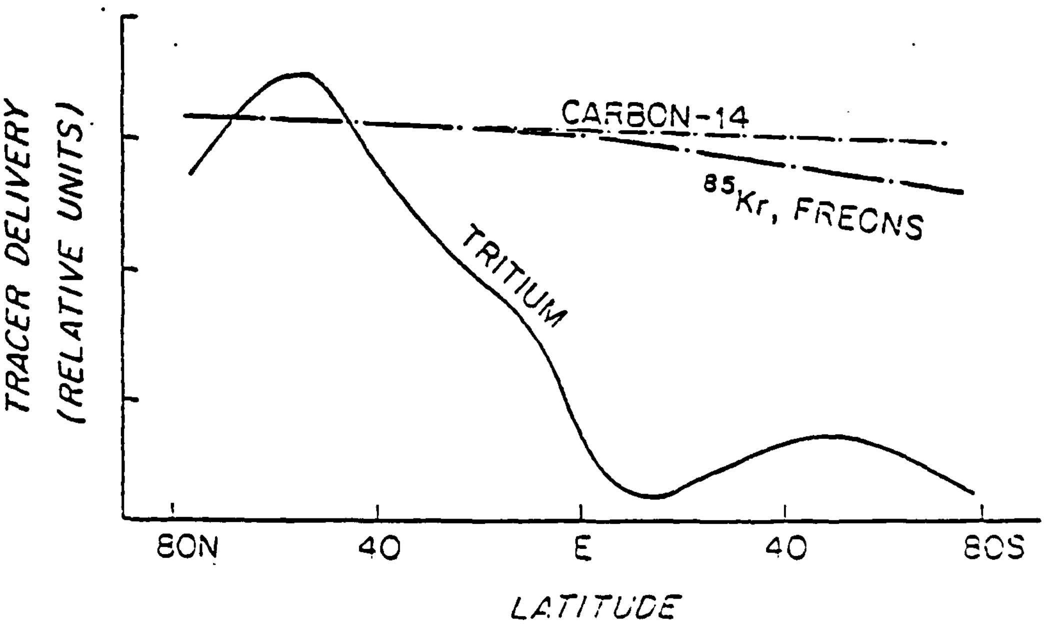


Figure 1b. Spatial patterns of transient tracer delivery to the oceans: approximate latitudinal dependence.

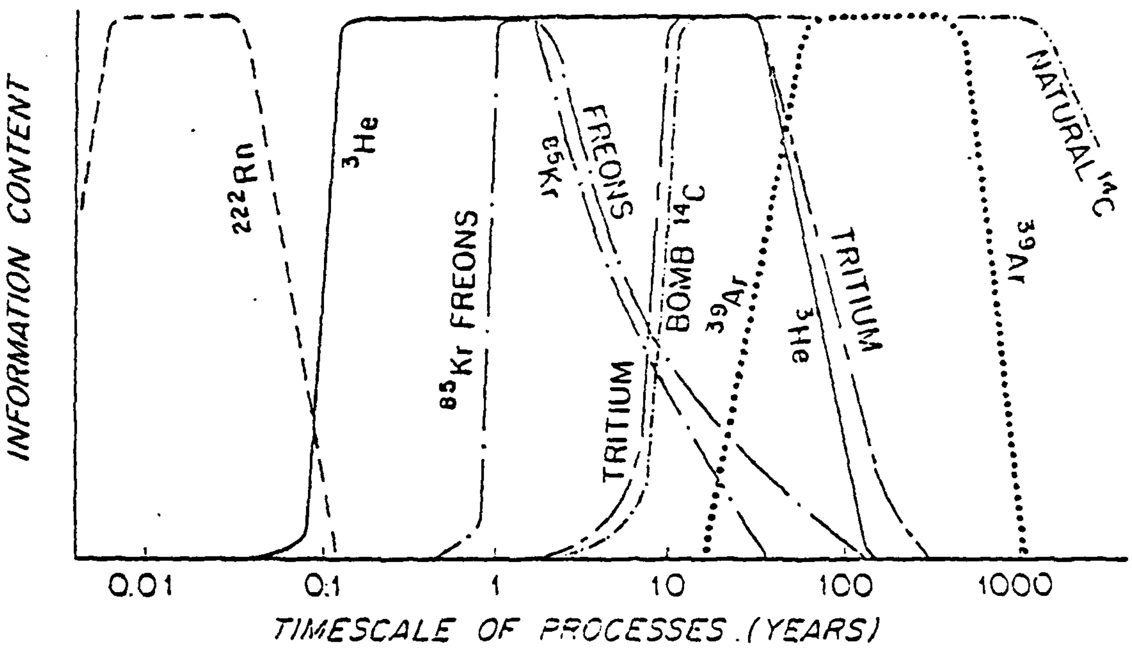


Figure 1c. A schematic representation of the information available from various ocean tracer distributions.

ciple, be performed on any scientific ship in conjunction witk work which involves normal bottle sampling. It is therefore c some of the work that we wish to perform in the coming years c cruises jointly with other projects with minimum interference ject. The World Ocean Circulation Experiment will, for exampl include measurements of nutrients, the carbonate system, triti freons.

Some special TTO cruises will have to be mounted, however, an overview of the carbon-14, krypton-85, argon-39 and radium- tions. This would require the use of big deep water samplers, the Gerard sampler. These cruises, therefore, probably will h formed on a sizeable ship such as the Knorr or Melville, while add-on complement for the "light" tracers can go on almost any

It is important that sampling be free of danger of contami labs can be contaminated by tritium and radiocarbon primarily and primary production studies in which large amounts of these used. The National Science Foundation is supporting a testing ships called SWAB, which has begun checking on levels of cont ships. Contamination levels can be orders of magnitude below levels, and still be threatening to the successful sampling a such tracers as tritium and ^{14}C.

B) Physical and Chemical Ocean Data Facility (P&CODF)

The usefulness of the tracer data is dependent on hav graphic and nutrient measurements. In the past 15 years, the

GEOSECS Operations Group, at Scripps, have developed the operation of chemical sampling, hydrographic, and nutrient measurements. For any other less experienced group to set up this sampling and measurement system would be a tremendous task and duplication of effort. We therefore recommend that this kind of service be kept available to the oceanographic community and the TTO program. We realize the present difficulties of P&CODF are caused by heavy demand on their services at a time of large cruises and slack in workload for months in a row in between. Under these circumstances, it is difficult to maintain continuity in staffing. The group must be retained at a level such that additional people from Co-PIs laboratories can augment a core of highly skilled people on the permanent staff of P&CODF during the cruises. It is also critical that the group be given resources and support for shore-based development and updating of their sea-going equipment so that data of the highest quality are obtained.

C) Laboratories

Highly sophisticated measurements of the transient tracers have been developed during the last two decades and a few U.S. laboratories have taken upon themselves to devote a large part of their time to measurements for the TTO project. At the University of Miami, Rosenstiel School of Marine and Atmospheric Science, the Tritium Laboratory is specially equipped to handle large numbers of tritium measurements by classical counting and radiocarbon measurements. For radiocarbon, the Quaternary Research Laboratory at the University of Washington is also equipped to measure carbon-14 with a precision of 0.3%, the needed resolution for this isotope. In addition to an existing facility for the measurement of helium-3 and the measurement of tritium by the helium-3 regrowth method, a new radiocarbon facility has now been constructed at the Woods Hole Oceanographic Institution. A ^{3}He system is presently being built in Miami. A krypton-85 measurement facility is presently being established at Lamont-Doherty Geological Observatory, and for radium and radon facilities are available at Lamont-Doherty Geological Observatory, Princeton and University of South Carolina. Furthermore, cooperation is established with University of Bern for measurements on krypton-85 and argon-39. The latter two measurements yield numbers that are of very high potential utility, but the quantity of samples that can be processed is small due to the very long time necessary for counting, and the large water volumes required.

D) Computers

There is a trend towards stand-alone mini and micro computers in the oceanographic community. Most research groups within laboratories have more or less sophisticated small computer systems for control of instrumentation, data handling and analysis, and some simple model computations. Intermediate and sub-mainframe systems such as the VAX level computers have proven valuable for small process oriented models and preliminary diagnostic calculations which eventually may graduate to larger scale or higher resolution studies. However, large computers are needed for the large-scale modelling efforts where one tries to construct models of large parts of the oceans with mathematical analogs of physical processes. Several institutions around the country are involved in this, and we have established cooperation with GFDL laboratory at Princeton University, NCAR at Boulder, and GISS in New York City.

5. Experimental Plans

A) "Global Studies"

Obtaining a large-scale quasi-synoptic description of the transient tracer distributions within the oceans is an important component to this program. This description, and its time evolution, will provide a powerful test of ocean circulation and climate models. Clearly, however, a truly synoptic picture is logistically unattainable; but comprehensive regional surveys within reasonably defined hydrographic boundaries, obtained in a rational sequence come very close to this ideal. The North Atlantic and Tropical Atlantic Studies are good examples of this, and the South Atlantic Study (see accompanying letter proposal) will prove an important follow-up. These surveys mutually provide the all-important boundary conditions necessary for interpreting the interior distributions. Also, the regional and global scale tracer distributions defined by these studies provide important background information to smaller scale studies.

The T.T.O.-South Atlantic Study is planned for the austral summers of 1983-1984 and 1984-1985. The first study involves a three-leg cruise aimed at characterizing the circulation of the South Atlantic subtropical gyre and the ventilation of its main thermocline. The rather different western boundary current system coupled with the significant invasion of Antarctic Intermediate water will provide informative contrast to the North Atlantic subtropical data; and obtaining an adequate picture of the tracer distribution in the southern subtropical gyre is an important southern boundary condition for the interpretation and modelling of the tropical/equatorial data. The second study will be aimed at determining the tracer properties in the area where

Gordon proposes that S.A.C.W. is ventilated; the region where McCartney proposes that AAIW is formed; and tracer-tracer relationships near the polar front. Establishing the "initial" or source conditions of the tracers in the formation regions is an important part of the overall program.

Some areas, due to the high density of scientific cruise traffic, will prove amenable to ancillary ("ship-of-opportunity") sampling. An example is the North Pacific where a number of ongoing research programs can be supplemented by tracer sampling. In this instance, a regional characterization of the main thermocline mixing processes may be obtained by observation of the vertical and lateral penetration of bomb-produced isotopes and freons. The large size of this basin, combined with the absence of direct ventilation of the central waters by air-sea exchange processes, allows the establishment of regional mixing domains which should be clearly identifiable on the basis of the tracer budgets and tritium-helium dating.

Figure 2 summarizes the overall time strategy of the larger scale surveys. Basically the plan is to complete the global coverage within about 10 years. Relationship with other programs (Section 7) is also indicated in the figure.

B) Process Oriented Studies

It is equally important to characterize the individual natures of the processes responsible for tracer transport. The reasons for deviations between model predictions and observations are often difficult to diagnose when many processes interact in a complex way. The efficient development of improved models is therefore dependent on the study of "simple" domains wherein one or at most a few processes dominate the tracer transient. These "test sites" allow the characterization of the specific building blocks - the pro-

Figure 2. Projected time table of TTO studies.

	T.T.O. Large Scale Study	Other Activities
	(GEOSECS) Indian Ocean	WBUC - Hatteras
1980		Beta Triangle Norpax Shuttle EPOC Beta Triangle
	T.T.O. North Atlantic (7 months)	Wunsch Trans-Atlantic Beta Triangle
	T.T.O. Tropical Atlantic (3)	Focal-Sequal McCartney-Warren Secns
	T.T.O. Subtropical South Atlantic (3)	Long-Lines WBUC-N.E. Seamounts S. Atlantic Beta Spiral
1985	T.T.O. Polar South Atlantic (3)	WOCE
	T.T.O. North Pacific (2)	
	T.T.O. Equatorial/South Pacific (4)	
	T.T.O. Indian Ocean (3)	
1990		
	T.T.O. North Atlantic	

cess representations - for the more complex complete models. Examples of such studies are extant in the literature and have provided the cornerstones of many sophisticated models.

Whereas the distinction between process-oriented studies and the larger scale ("global") surveys is somewhat ill-defined at times, the more process oriented studies tend to lean more heavily toward spatially focused, time-intensive measurements, although not exclusively so. Small scale mapping of hydrographic and tracer data can be usefully coupled with beta-spiral type studies, particularly when the regional gradients in the tracer fields are well documented. Process studies in the boundary regions which include joint current-meter and tracer measurements have proved fruitful as well. Future directions should include close collaboration with float dispersal and deliberate injection (DOTREX) experiments, as well as CTD-intensive frontal studies for mesoscale processes. The smaller scale work will be especially effective when tracer-tracer corellations are established on a background of larger scale tracer gradients. These shorter timescales may be seen (in the Northern Hemisphere, at least) using the tritium-helium pair.

C) Time Histories

A complementary approach to obtaining quasisynoptic large-scale maps of tracer distributions at order decade intervals is that of obtaining relatively high frequency (sub-annual) data of more limited spatial extent. Examples of this are the weather ships (for meteorological data) and the Panulirus Bermuda Station (for hydrographic data, and since 1977 tritium-^{3}He). On a grander scale, perhaps with less frequency, repeated sections can be obtained. Such approaches tend toward more process oriented information as well as climatic and statistical (spectral) content, and lend a new dimension to the larger scale studies. The optimum location of these sites is in areas of well defined, large scale, relatively well mixed hydrographic domains, e.g.: subtropical gyres, marginal basins (Labrador Sea). Formation areas and straits might be considered, but the possibility of very short timescales aliasing the record make this difficult. Logistically, proximity of islands with well run hydrographic facilities (e.g. Bermuda, Iceland, Hawaii) make ancillary tracer sampling attractive. Establishing a coherent multinational strategy should be a high priority item.

Also at our disposal is the measurement of certain isotopes incorporated into growth bands in corals. ^{14}C and ^{90}Sr records are emerging which may give a detailed history of the impingement of those bomb isotopes on the surface ocean. Furthermore, the imprint of the Suess effect on the pre-bomb ^{14}C inventory is evident. Further study of these isotopes will provide important constraints on the generation and delivery of these isotope inventories, and on air-sea carbon isotopic exchange, as well as potential climatic modulation of the latter.

6. Modelling and Interpretation

The large scale mapping of transient tracer distributions can be used for the purpose of estimating the likely oceanic invasion patterns for any other trace substances with identical or similar surface delivery patterns. Simple "analog" models have been and will continue to be constructed which mimic the observed penetration of some tracers and predict the penetration of others. As the number of tracers measured increases, and as the already observed distributions are seen to evolve, the constraints on such models will become more severe, increasing our confidence in the successful analogs. The use of such simple devices is more as a conceptual framework within which to pose more complex models, or to design future observational programs, rather than as truly prognostic devices.

Further, the observed distributions may be used as touchstones for the performance of predictive and dynamical models. Much thought, however, must go into the posing of these models, particularly in the all-important boundary conditions to which "model tracers" can be so sensitive. In addition to the sensitivity to the often ill-behaved boundary problem, such tracers tend to be operated on by second order parametric processes such as eddy diffusion which are usually introduced into the dynamical model in an heuristic way. The use of high resolution multidimensional turbulence models places heavy demands on computational facilities and at present, only small domain experiments are viable. Optimistically such prognostic numerical experiments will migrate spatially upscale toward at least basin scale domains, and by careful "patching" of boundary regions, might evolve into an Ocean General Circulation Model.

Larger scale diagnostic models have and will continue to be a useful endeavor, and attempts to match tracer predictions with reality will be instructive in providing integral constraints on the processes acting on the tracers, and in designing future measurement programs. Improvement of the models, particularly in posing of boundary conditions and parameterization of subgrid-scale effects can be expedited by careful consideration of process oriented studies and specific observational tests in critical areas. The mutual enhancement of large and small scale (global and process oriented) studies should not be overlooked.

The inverse technique, as introduced to oceanography by Wunsch, appeared quite promising at first, but the sensitivity of the technique to noise in the data and non-synopticity has presented problems to be overcome. Transient tracer distributions will provide very powerful constraints to the calculations, and work is underway to develop an appropriate formalism for their inclusion.

Finally, it should be noted that to the first order, many of the transient tracer distributions appear similar, and the more successful diagnostic and analog models, inasmuch as they are generally "tuned" to the tracers, predict much the same features. It is, in fact, the subtle differences between the tracers, generated by their differing boundary conditions, that are important. The geometric patterns produced by the predictive models also tend to suffer from uncertainties introduced by scaling and boundary conditions. Consequently it should be kept in mind that tracer-tracer relationships (e.g. ^{3}H vs. ^{3}He or ^{14}C vs. ^{90}Sr) provide important tests of models and process parameterization.

Entrainment of theoreticians and modelers into all stages of the program - planning, execution, analysis and interpretation - has taken a high priority and is meeting with early success. We are continuing this approach with a view that the natural feedback between all stages of this work enhances the overall program.

7. Relationship to Other Programs

A variety of linkages quite naturally exist between many of the participants and other programs anyway. In an informal way, ancillary tracer sampling has been and will be occurring on many programs, e.g. the Long Line Sections, ISOS, NORPAX. The paralleling of goals and techniques will ensure a continued cross-pollination of ideas and activities.

Involvement of TTO in the CCCO-WOCE is already started, and sampling is planned for the duration of the 5 year experiment. Sampling is currently planned on the FOCAL cruises as well as the Long Lines sections. Cooperation with West Germany (University of Heidelberg) has been long established and co-operative work during T.T.O.-N.A.S. was carried out. The Icelanders and British are being approached about establishment of time-series stations.

8. Management

The effective execution of this program depends on a well structured management. (See Figure 3). Overseeing the program resides with the Steering Committee whose primary responsibilities are to:

a) act as interface between the P.I. group as a whole and the agencies;

b) ensure co-ordinated and efficient implementation of the different experiments, and establish an overall policy regarding data management, dissemination and quality control;

c) facilitate contacts with other programs, particularly international ones;

d) orchestrate periodic meetings of the P.I.'s and to initiate and organize new incentives, as well as entraining new P.I.'s into the program.

The Committee is elected by the P.I.'s and as the overall program evolves,

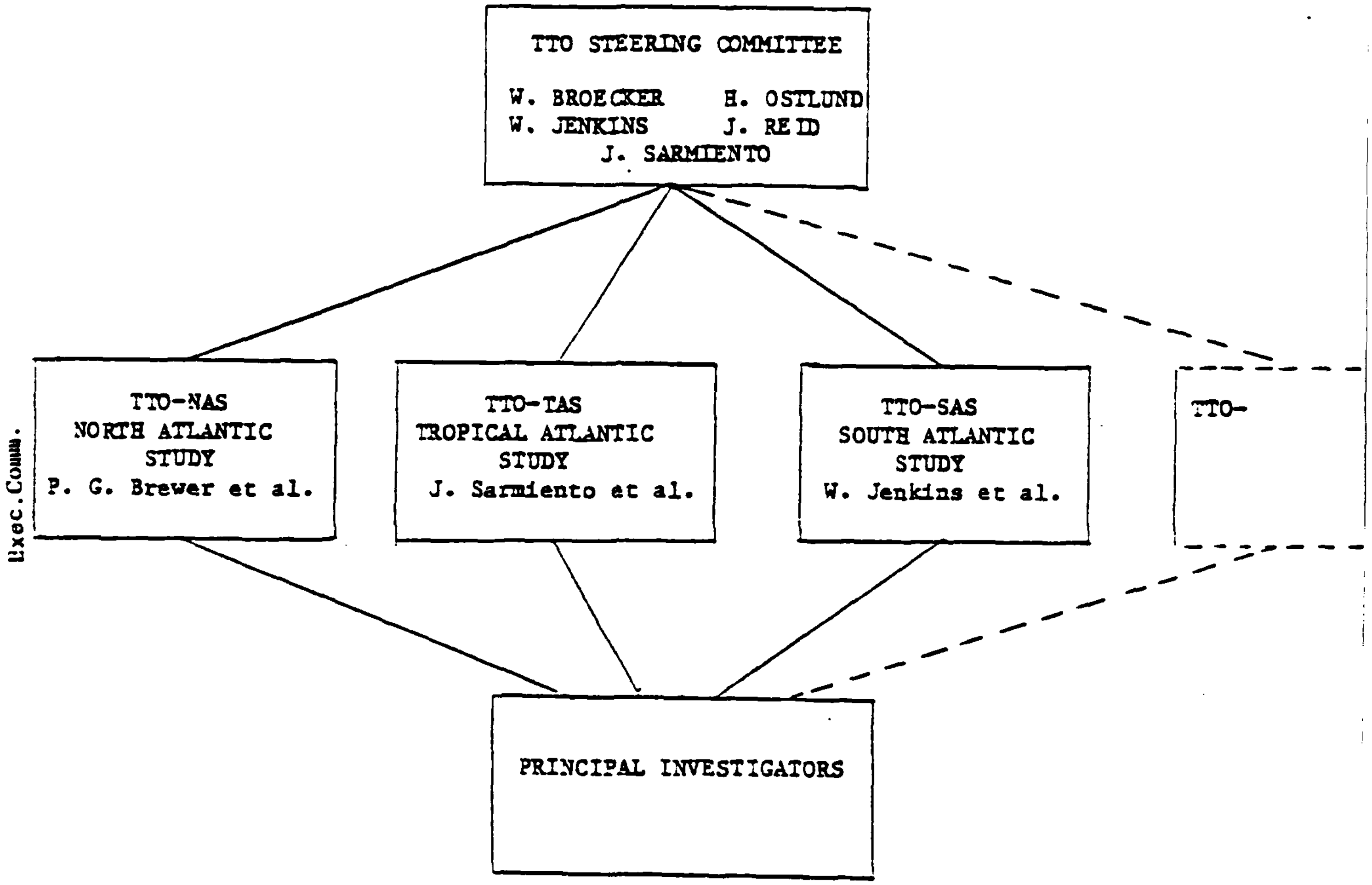


Figure 3. Management Structure

will change in membership. The present makeup was aimed at establishing reasonable representation by discipline and institution. At present it consists of:

W. S. Broecker	Lamont-Doherty Geological Observatory
W. J. Jenkins	Woods Hole Oceanographic Institution
H. G. Ostlund	R.S.M.A.S.
J. L. Reid	Scripps Institution of Oceanography
J. Sarmiento	Geophysical Fluid Dynamics Laboratory

There is necessarily a preponderance of geochemists (W.S. Broecker, W.J. Jenkins, H.G. Ostlund) due to the emphasis on measurement, but there is a numerical modeller (J. Sarmiento) and physical oceanographer (J.L. Reid). Of the three more experienced members, two have been directly involved in management of the GEOSECS program and hence have useful experience with such programs.

Beneath the Steering Committee is an Executive Committee created for each specific experiment. Each committee has a co-ordinator/spokesperson who is responsible for organizing and carrying out the experiment, as well as for planning and preparing the proposal overview, etc. We are having semi-annual "data-exchange" meetings to enhance interaction between P.I.'s, and hope to have special A.G.U. sessions relatively often (every year to year and a half) to disseminate data and ideas. The most recent data meeting took place at Woods Hole in April and an A.G.U. session is planned for this fall.

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LONG LINES: A Program of Oceanographic Stations

by: Reid + Nowlin

Introduction

There are many areas of the ocean in which the coverage by modern hydrographic stations is not adequate to describe the large-scale distributions of characteristics and general circulation. It appears that we know so little about the zonal circulations at subsurface depths--we have only the vaguest qualitative picture--that even the best modelers or analysts might be led astray by the present data bank of principally zonal sections. Some yet unanswered questions about the North Atlantic are: Does the Gulf Stream (or North Atlantic Current) really extend east of the Mid-Atlantic Ridge at depths down to 3000 m? And does the Gulf Stream recirculation begin in the eastern half of the Atlantic? How far east? And what is the real circulation that accounts for the pattern of the Mediterranean salt tongue? Even a single meridional section placed properly might do much to resolve these issues.

Modern stations must include vertical sampling from the surface to near the bottom, of T, S (with modern salinometer), O_2 and nutrients at least. Sampling for other variables should be included as appropriate and where feasible, considering time constraints. CTD profiles should be taken, and must be supplemented with bottle data at intervals generally not to exceed 250 m but adequate to define the major features in water-mass and density structure.

We have suggested (to the Committee on Climate Change in the Ocean and to the NAS/OSB Steering Committee for a U.S. Ocean Climate Strategy) a series of sections of such hydrographic stations which would help fill data gaps in the world ocean. This recommended series does not include all the sections that would be desirable, but it represents those to which we assign highest priority.

We are aware that others are also interested in such work and have or will offer ideas and proposals. For example, Henry Stommel, Carl Wunsch, James Luyten, Mike McCartney and Bruce Warren are planning hydrographic sections in the Atlantic Ocean during 1982-1983. We see no conflict developing, but rather a desire to accommodate with individual studies the needs of all of us who are concerned with the general circulation.

The sections are seen (Fig. 1) to be more numerous in the So
in the Northern Hemisphere. As there are fewer data there, those
are meridional or nearly so. The orientation of new sections shou
principally by what we conjecture or wish to learn about the flow
should be normal to the flow; near the continental boundaries they
normal to them; in the interior they should be nearly meridional,
zonal part of the major gyres; and the deepest flow must be studie
sections oriented across the channels. No single section is likel
these needs.

We believe the greatest limitation is in our information abo
lation of the major mid-ocean gyres, whose zonal components are no
represented by the present data bank. Recommended are those that
will give the most useful improvement in our concepts of the gener
and this, in turn, will help in planning other work.

We believe that in most cases horizontal spacing of stations
1° latitude, except in regions known to have narrow, but significa
density gradients in which supplemental CTD casts should be made.
sections connect continental boundaries. Others could be extended
way so as to allow estimation, by the inverse method, of absolute
and transports through these sections.

Proposed Program

We propose field measurements to describe selected phenomena
circulation features and distributions of characteristics in the S
and South Pacific oceans. The program is structured around sampli
of the recommended large-scale sections in the Atlantic (Fig. 2) a
Pacific (Fig. 3). Because other oceanographers are making long li
in the North and South Atlantic in 1982 and 1983, we propose to pr
the Atlantic work first.

Atlantic Sampling Plan

The Atlantic trackline is shown schematically in Fig. 2. To
[illegible] in the regions of sea ice, the cruise might begin from Af
[illegible]tral summer. In order to extend the Greenwich meridian s
[illegible] ice limit, a port stop (perhaps in Capetown) will be
[illegible] South Atlantic will include an E-W section through the
[illegible] from the southern end of the Greenwich meridian sec

Eastern South Atlantic Circulation. The patterns of flow in the eastern South Atlantic have been studied by fewer people than those in the north. There is still a considerable divergence of opinion, and probably for the same reason--not enough information. From the coast of Africa at about $7^{O}N$ the section extends across the equatorial zone, with the Guinea Current, equatorial undercurrent, a westward flow 0^{O} to about $5^{O}S$, a South Equatorial Countercurrent (according to the Soviets and French, but not to most U.S. investigators), another westward flow, a very uncertain pattern around the zone where a major anticyclonic pattern may extend and then into the Antarctic Circumpolar Current. All of these features require a higher resolution in the meridional gradients before any conjecture, old or new, can be justified. The nature of the flow, its strength and the depth to which it extends, the apparent poleward extension of the anticyclonic gyre at depth as indicated in the Meteor Atlas, require a better data base. Will it have patterns of flow analogous to those of the North Atlantic or will a substantially different system emerge?

If the Greenwich section is extended to southern ice limits in summer, then the section would extend from the African Coast to the Antarctic Coast (at 0^{O}) and could be used to calculate velocities by the inverse method.

Near Bottom Waters; Exchanges Between Basins. In addition, there can be various sub-studies using data from Greenwich meridian transect (between $7^{O}N$ and $55^{O}S$). Stations in the Guinea Basin (just west of 0^{O}) will contrast the basin waters across the Guinea Ridge (in Guinea and in Angola Basins). Better hydrography near the gap in Walvis Ridge between Angola and Cape Basins will provide information on the exchange there. The region of a possible break in the Atlantic-Indian Ridge can be examined by study of basin waters to either side in the Cape and Antarctic-Indian Basins. Better-defined patterns of near-bottom characteristics in the eastern South Atlantic may suggest more details in the abyssal flow there.

Southern Ocean Studies. A section across the Weddell Gyre with complete nutrients would help define the strength (as seen by the patterns of characteristics) and the extent of this gyre. Modern sections across the Antarctic Circumpolar Current system are needed in order to assess the degree to which observations from Drake Passage and south of New Zealand apply to other Southern Ocean regions. Station spacing will be supplemented by added shallow CTD casts to ACC fronts.

Additional stations on and beside Maud Rise should help determine the zonal flow past and over this bathymetric high extending northward from Antarctica.

Scotia Sea. Quality data are needed from the deep waters of the central and eastern Scotia Sea for comparison with data taken south in the Weddell Sea and to the east and north of the Scotia Arc. Perhaps exchanges and their paths through breaks in the Arc can be better determined. Existing sections in Scotia Sea are mainly north-south and are difficult to combine for study of regional distributions--perhaps in part because of time difference and in part because of data standardization or quality problems. An east-west section tied to known, well-established distributions at Drake Passage should allow intercomparison, and perhaps composite usage, of these existing sections.

Pacific Sampling Plan

The proposed sample line begins at the west coast of Mexico at 100°W and proceeds nearly southward to the Antarctic ice edge. One port stop in Chile is required during this part of the work. From 100°W at Antarctica the ship will proceed without stations to 150°W at the Antarctic ice edge. From that position stations will be made northward to Hawaii. That section will be interrupted for a port stop in New Zealand and will include two special sections and the deployment of current meter arrays in the western boundary region near New Zealand.

The entire cruise would require approximately 130 days at sea in three legs, including time for nearly 160 stations and time during leg three for the deployment of moored arrays. To obtain data as near to Antarctica as possible, the southernmost stations should be made in mid to late austral summer.

The moored arrays deployed on this first cruise would be recovered after a period of 12 to 18 months. For that work we will try to obtain assistance from New Zealand scientists and use of the research vessel TANGAROA. During the recovery an attempt should be made to obtain additional stations across the deep western boundary current of the western South Pacific.

Scientific objectives

A general objective of the Pacific sections would be to add to modern, large-scale oceanographic data coverage of the world ocean. The proposed stations will fill in the most obvious gaps in modern oceanographic data in the South Pacific. This should be done, and the resulting expanded basin-wide data set should be studied as background for the design of future programs to monitor the general circulation and its variability. These long sections should prove useful in future general circulation experiments using satellite altimetry.

In addition the data collected during this South Pacific field work can improve our knowledge of many phenomena and features. The following expanded outline indicates the uses to which we intend to put these data.

The descriptions of South Pacific general circulation features can be improved. From earlier studies, a reasonable but uncertain portrait of the circulation in the central South Pacific has emerged. Measurements along 155°W would pass through the principal north-south gradients in this circulation pattern and could be used to verify or improve it. In the eastern basins of the South Pacific the available patterns of characteristics do not define the circulation pattern unambiguously but seem to indicate north-south pressure gradients which could be verified by the section of stations along 100°W. Taken together with existing data, the new measurements should allow better determinations of: the spatial extent of the closed Ross Sea gyre (a cyclonic wind-driven feature?); the northward extent of deep water recirculation in the western basin (a thermohaline circulation feature?); and a much better evaluation of the strength and depth of the zonal limbs of the anticyclonic gyre.

Much remains to be learned about the deep and near-bottom water circulation of the South Pacific. In the eastern South Pacific the new measurements will help determine the routes of deepest water exchange between the several basins (which bathymetric gaps are controlling the exchanges) and the influence of these exchanges on the property distributions. In the western South Pacific it is important to determine the sense of direction of the long-term flow as a function of depth in the deep water. In this way it will be possible to assign more realistic reference levels to the geostrophic flow fields calculated from density measurements in this region. In the interior and on the eastern flank of this western basin it is not known whether the deepest water is flowing generally southward, thus providing some cyclonic closure to the northward-flowing deep western boundary current, or northward, thus indicating that the only likely southward return for the northward-flowing near-bottom waters is at deep or intermediate levels. Long-term current measurements through the intermediate to bottom waters at several sites along the western basin should suffice to determine the sense of the long-term flow, if not to estimate its vertical profile of speed. Using these mean flow directions and the existing density fields, our knowledge of the general circulation of the deep and near-bottom waters can be improved. The current and temperature measurements can also be used to provide first estimates of variability at these positions.

Using the station data along the eastern section from 5^{o} to 20^{o}S near the East Pacific Rise, a question regarding heat flux can be considered. Heat flow from this Rise seems to affect the mid-depth distributions of characteristics near 18^{o}S westward into the central Pacific. What is the extent of the effect of heat flow from this region on property distributions--to the east as well as west?

Finally, the program will provide added data for study of the Antarctic Circumpolar Current (ACC). During the past five years studies of the Southern Ocean have shown the ACC to be characterized by several rather narrow (~50 km) equivalent barotropic current cores which separate more nearly uniform water mass regimes in which the net eastward currents are relatively weak. These are observed to move laterally, meander and form current rings which may be a principal mechanism for the meridional exchange of heat and other properties across the ACC system. To date north-south sections with station spacing close enough to resolve this horizontal structure have generally been limited to the Drake Passage and the area south of New Zealand and Australia. To determine whether the recent results are truly representative of the entire circumpolar area additional sections across the ACC are needed in other regions, especially those south of open ocean rather than in regions constrained by land masses or topographic barriers. The proposed Pacific sections, and particularly that near 100^{o}W which is in a region of minimum bathymetric variation in the Southern Ocean, will help answer this question. For this purpose it will be necessary to take additional upper level CTD stations in the regions of horizontal fronts which can be determined from XBT measurements. In general these new sections should allow a better understanding of the relation, particularly mass exchanges, between the circumpolar current system and the mid latitude circulation of the South Pacific.

Summary

Several sections have been proposed, and four have been discussed in a little more detail, including some of the particular features. Each of these features could be treated as a problem on its own, and merits a good set of measurements (including oxygen and nutrients) to determine gradients across the various flows. A long section that crosses a set of such features in sequence, with a single set of equipment, reagents, and personnel, would provide a whole that is much greater than the simple sum of its parts when addressing the problem of the general circulation.

The other sections in the Pacific and Indian oceans will not be discussed in detail: the need for some such array is obvious. In particular, Klaus Wyrtki would certainly have been pleased to have such sections in the preparation of his Indian Ocean atlas: his ideas should be sought as to the exact placements. Those in the Pacific are laid on at present simply to fill in the gaps in coverage, especially in terms of the major gyral flow.

We hope that several investigators will be interested in carrying out some of these lines, either for the general circulation or in conjunction with particular regional problems, and that within the next few years the data bank will be augmented with hign-quality data along the critical lines.

J. L. Reid and W. D. Nowlin, Jr.

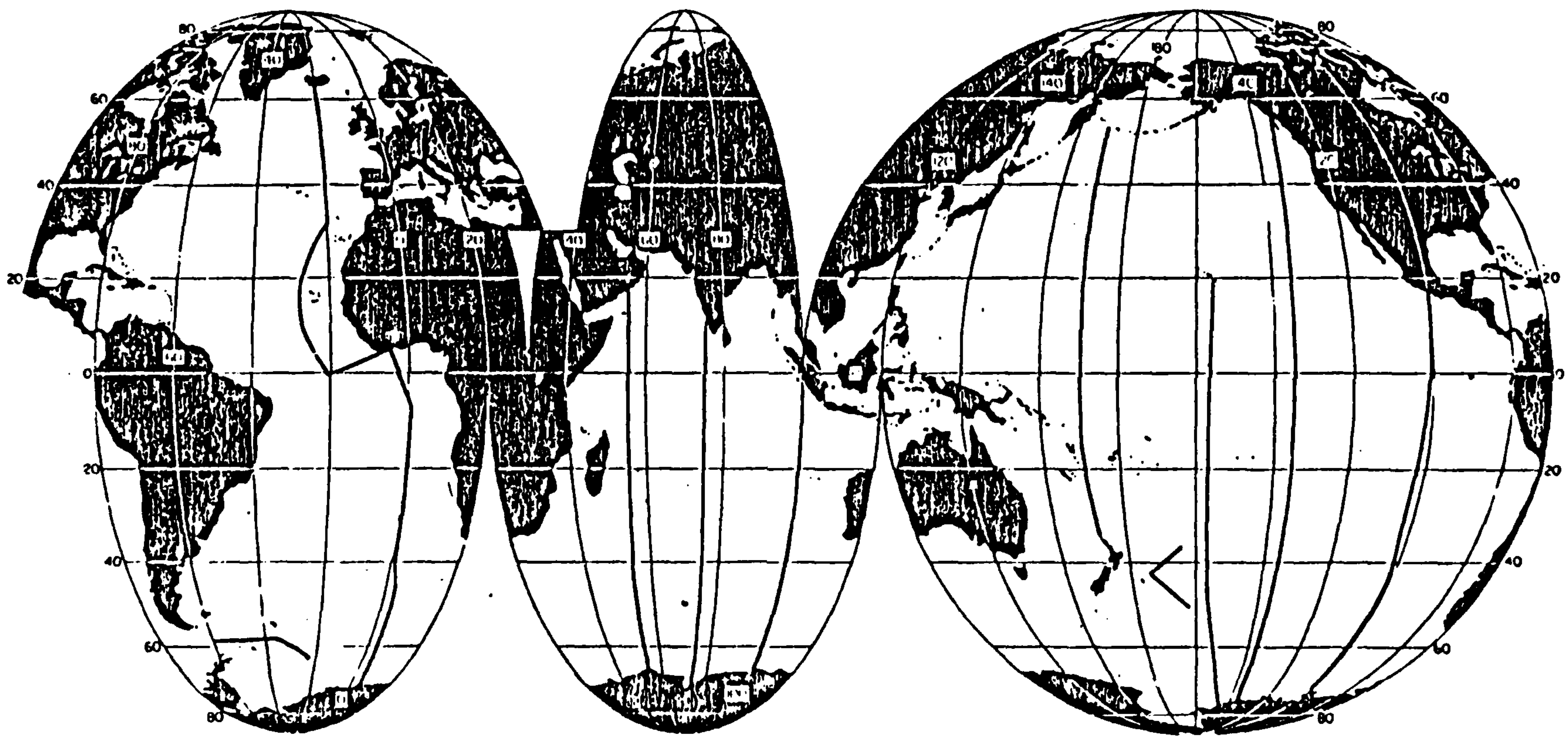

Fig. 1. Sections along which complete modern oceanographic stations at approximately 60 n. mi. spacing are suggested to improve knowledge of general ocean circulation and characteristic distributions (temperature, salinity, oxygen, phosphate, silica, nitrate, and stability).

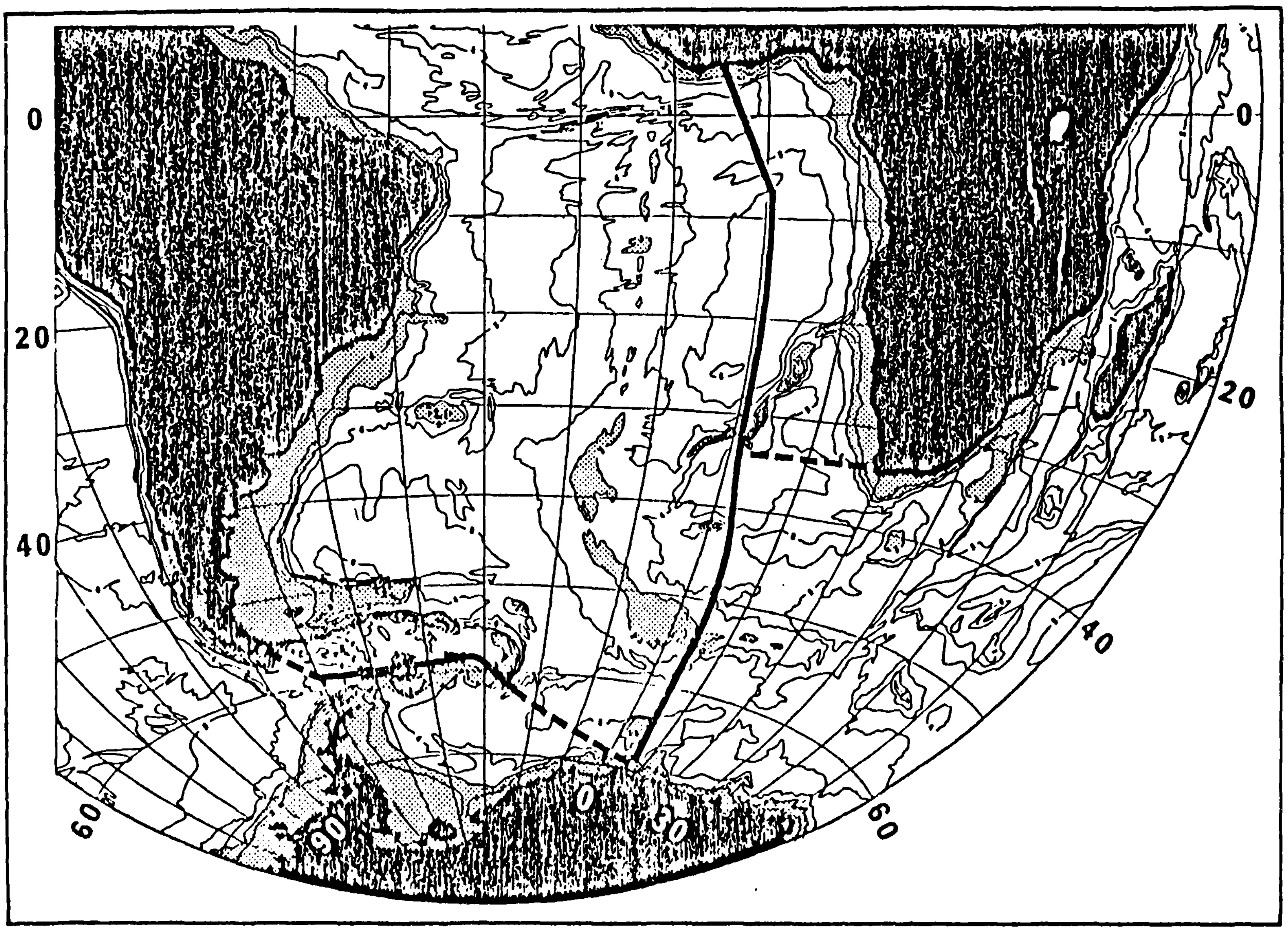

Fig. 2. Cruise track for proposed S. Atlantic field work. Station sampling will be carried out along solid portions of track lines.

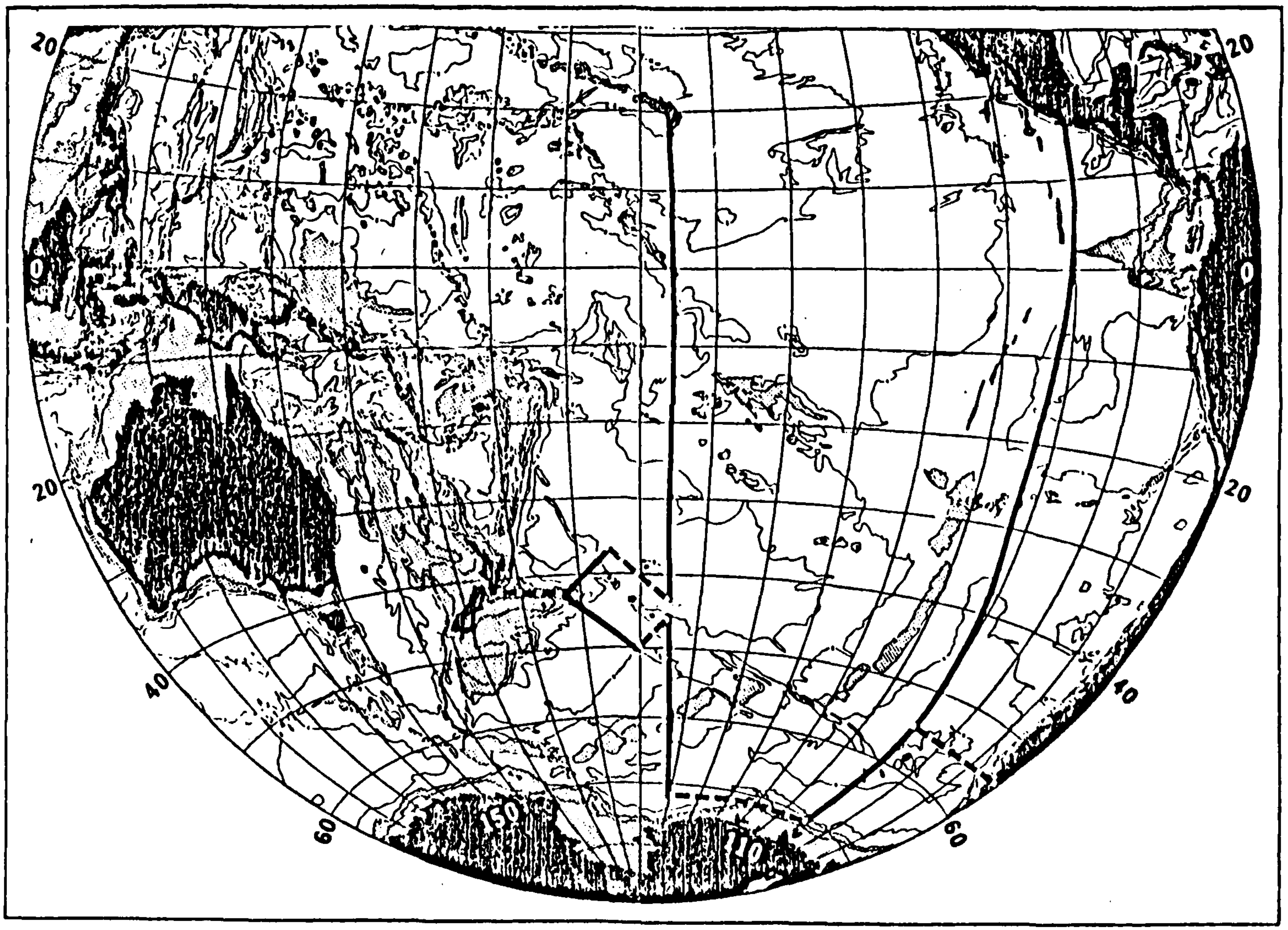

Fig. 3. Cruise track for proposed S. Pacific field work. Station sampling will be carried out along solid portions of track lines.

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Woods Hole, MA 02543
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February 10, 1983

Dr. Arnold Gordon
Lamont-Doherty Geological Observatory
Palisades, New York 10964

Dear Arnold:

Thank you for the invitation to the February 22-23 meeting to consider a program for the South Atlantic and Indian Oceans. Unfortunately I will be at sea (SEQUAL 1) on your ship and cannot attend. Breck Owens plans to come and he can outline an experiment using SOFAR floats and drifters.

Our aim should be to obtain some of the same kinds of data in the Brazil-Falkland system that we have been getting in the Gulf Stream system. This is so we can make a direct comparison of the characteristics of the Gulf Stream with those of the Brazil-Falkland current system (and/or Agulhas Current). The objectives described in the Southern Ocean Studies research option seem like important ones to me. Specifically we need to measure, describe and model features of the general circulation (such as the size and shape of the Brazil Current, its overshoot, its recirculation), the time-mean velocity field, the velocity variance (eddy kinetic energy) at several depths, the number, distribution, intensity, and movement of current rings. My personal interest is primarily in the Brazil-Falkland confluence zone and subtropical gyre although the Agulhas, its retroflexion and ring shedding also seems scientifically interesting.

<u>Measurements</u>

1) <u>Analysis of historical data</u>. One of the first studies that needs to be done is to take a careful look at historical data such as XBTs, hydrographic stations, ship drift velocities, FGGE drifters. An analysis of these could help pinpoint certain features and be a help in planning field experiments. Maybe some of these historical data sets are being analyzed at present(?).

2) <u>Synoptic scale features</u>. I would like to see a few characteristic synoptic maps of the Brazil-Falkland region as measured by AXBTs or XBTs. Just what is the shape of thermocline (geostrophic shear), the path and structure of the currents, the size, shape, and location of warm and cold

rings? How far can the Brazil Current be traced eastward as a jet? What is the size and shape of the Brazil overshoot or southward bulge of warm water seen on IR images? Several such maps made at different times over a year could give pictures of the system and how it varies in time. Hydrographic sections and velocity measurements with drifters and deeper floats would be valuable in enhancing and interpreting these synoptic views.

3) Direct current measurements - drifters and floats.* Drifters and SOFAR floats have given exciting new informaton about the Gulf Stream system and they would be even more informative in the Brazil-Falkland system where no other current measurements exist. These instruments provide quasi-Lagrangian trajectories and velocities in specific synoptic scale features (current jets, meanders, rings, etc.) as well as outside the features (in the North Atlantic Deep Water for example). In combination with simultaneous AXBT, XBT, IR images these kinds of measurements would give much new information about synoptic scale events in the Brazil-Falkland system.

When drifter and float velocities are grouped together into space-time averages we can obtain a measurement of the mean velocity field and eddy statistics. One of the most useful results of a float and drifter experiment would be the measurement of the geographical distribution of eddy statistics at several depths (surface, 700 m, 2000 m) with which we could make a direct comparison to those of the Gulf Stream system and to the results of models of ocean circulation. We are presently tracking SOFAR floats in the Gulf Stream and are generating maps of eddy statistics.

A reasonable number of instruments for a first look at the Brazil-Falkland system is approximately thirty surface drifters and approximately thirty SOFAR floats (set at 700 m and 2000 m, as in the Gulf Stream). It seems logical to launch some drifters and floats in both the Brazil and Falkland currents upstream of the confluence zone and also some in the vicinity of the confluence zone approximately 40°S and a few in rings and other features/areas of interest. It is probably a good idea to make two deployments in time about six months apart for surface drifters (15 each time). This would give two realizations of the swift currents regimes and a measure of seasonality.

Breck Owens can discuss with you a SOFAR float component. We are presently preparing for an experiment in the Eastern North Atlantic which will begin in 1984. Breck is planning an experiment in the North Atlantic Current which would begin in 1985. With these activities the earliest we could get SOFAR floats into the water in the South Atlantic would be late 1986 or 1987. The float work would need lots of deck space on a medium

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* Some moored current meter measurements would be good to have, but, in the Brazil-Falkland confluence zone, I don't know where to place the moorings.

or large ship. We would need shiptime to moor approximately four listening stations and to launch the floats. The moorings would be supplemented by a few RELAY stations (floating buoys that transmit data via satellite). We would track the floats for about three years.

Surface drifters could be purchased from Polar Research Lab and launched whenever ships are available (given 6-12 months lead time). Drifters have a life of one to two years. Presently a less expensive drifter is being worked on. It might be operational in time for studies in the South Atlantic.

In summary I envision a program concentrating on the energetic Brazil-Falkland confluence zone (or possibly Agulhas Current retroflexion zone). The currents would be mapped with AXBT and XBT and some Hydrographic sections taken. Currents would be measured by surface drifters and SOFAR floats. These data would provide us with a basis to make a better description of the Brazil-Falkland system and to make a good comparison of it with the Gulf Stream system.

Yours truly,

Phil

Philip L. Richardson

PLR:mal

cc: Breck Owens
Lou Goodman
Tom Spence

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